Comparison between CERES-CALIPSO-CloudSat-MODIS (CCCM) and CloudSat-Lidar Products and Its Implications

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Objectives

- Compare CERES-team-produced CERES-CALIPSO-CloudSat-MODIS (CCCM) and CloudSat-team-produced CloudSat-Lidar merged cloud properties
  - ✓ Cloud Fraction
  - ✓ Cloud Optical Thickness
  - ✓ Cloud Particle Size

- Examine how the different cloud properties produce difference cloud radiative effects in CCCM and FLXHR-LIDAR

- Suggest possible ways for improving CCCM flux and heating rate computations for cloudy atmosphere

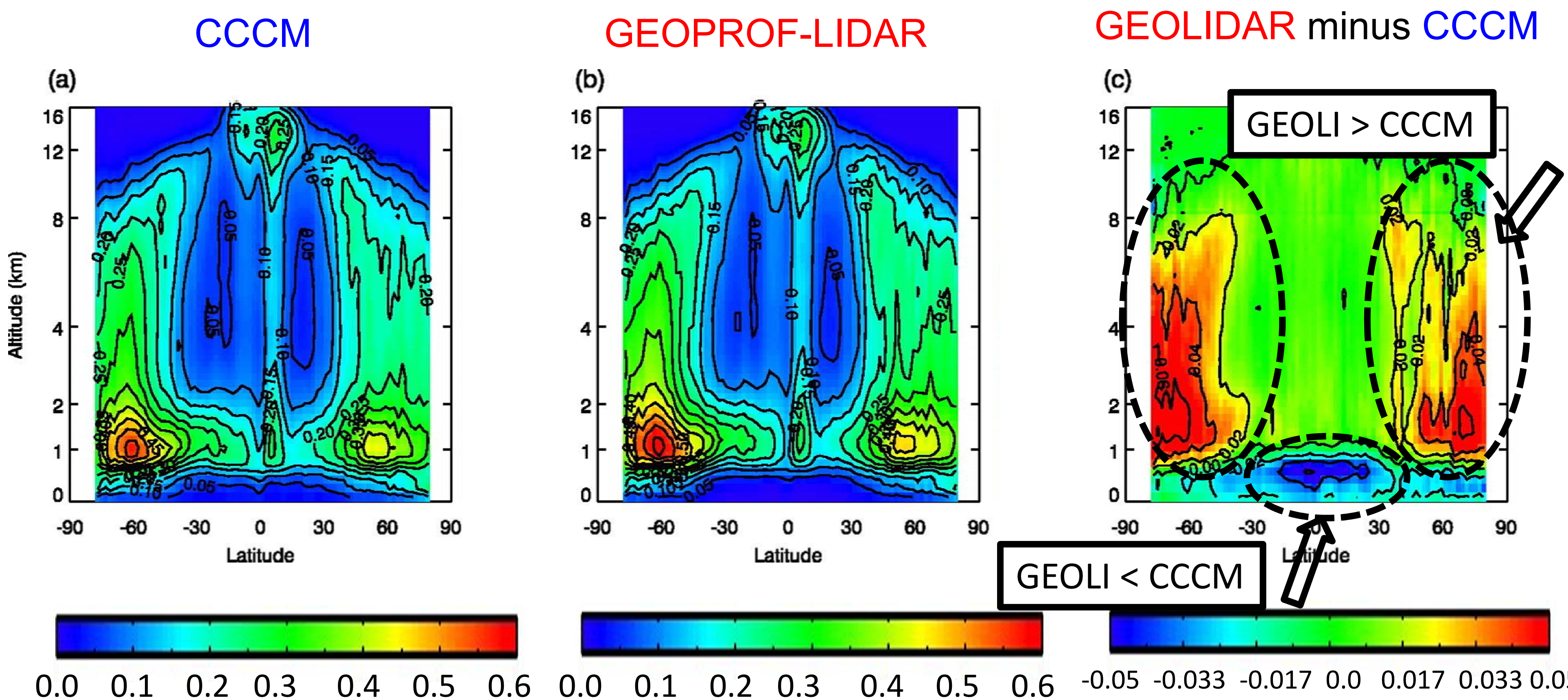
Datasets

1. CERES-Team Products: CERES-CALIPSO-CloudSat-MODIS (CCCM)
   - Spatial resolution of CERES footprint (~ 20 km)
   - Vertical resolution of CALIPSO (30 m or 60 m)
   - Primarily use CALIPSO for assigning cloud boundary
   - GOES-4 Atmospheres for flux computations

2. CloudSat-Team Products: 2B-GEOPROF-Lidar, 2B-FLXHR-Lidar, 2B-CWC, 2C-ICE
   - Spatial resolution of CloudSat footprint (1.4 km x 1.1 km)
   - Vertical resolution of CloudSat (~480 m, every 240 m)
   - ISCCP Atmospheres for flux computations

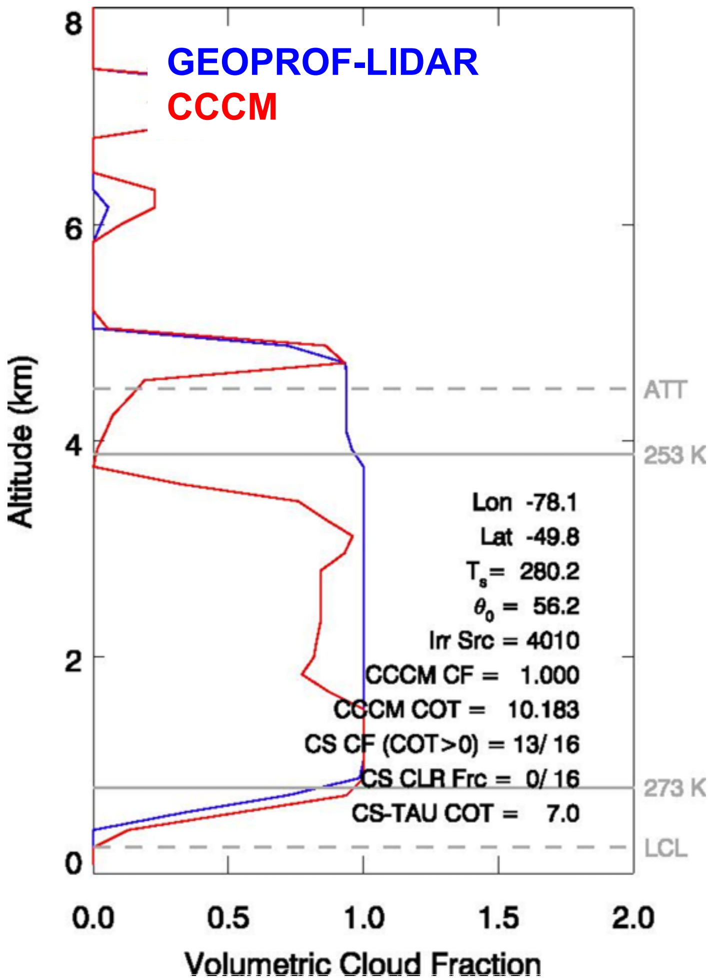
Except TOA radiative closure, we will compare [all minus clear] fluxes to exclude impacts of different atmosphere and surface properties.

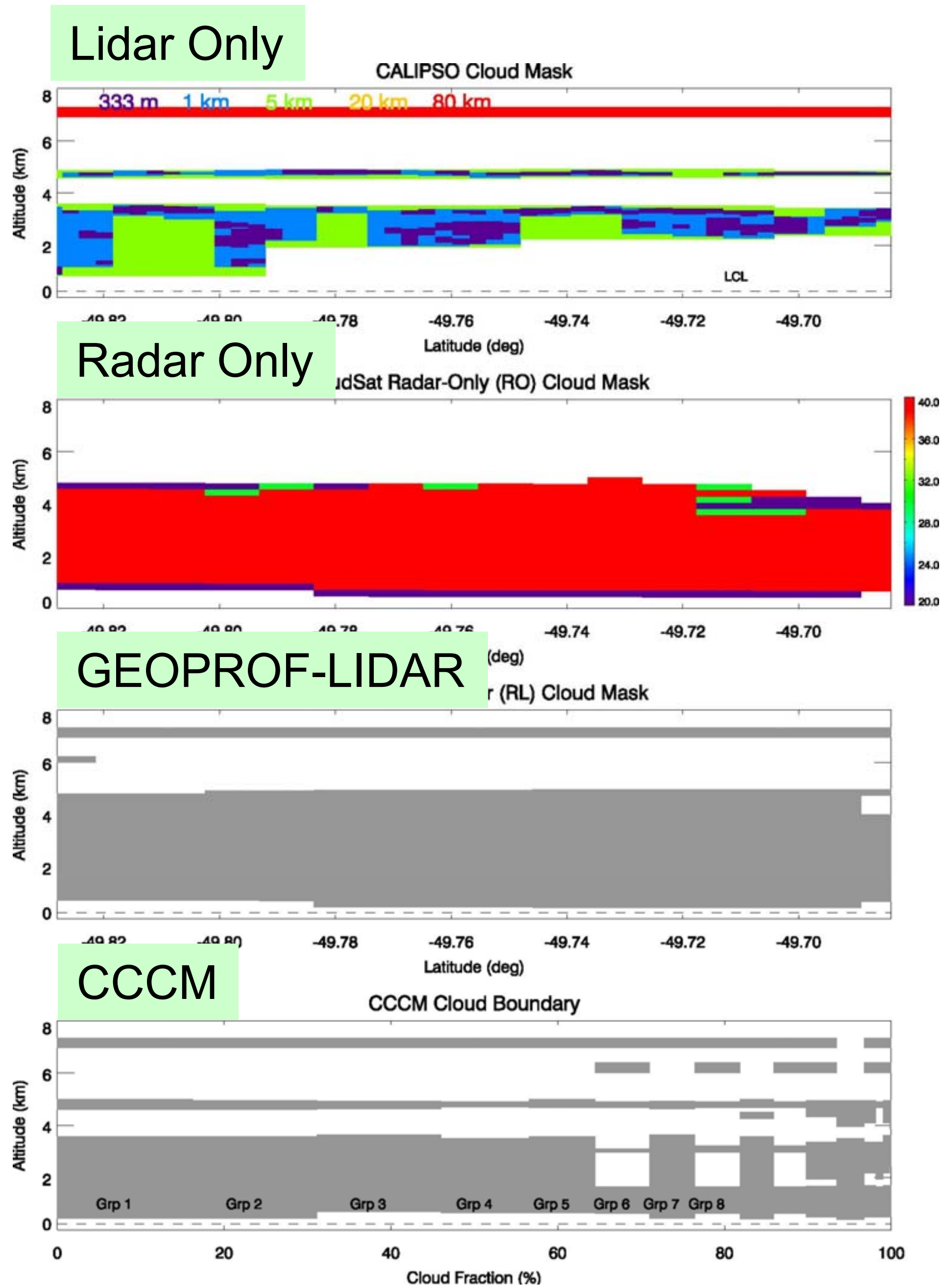
Volumetric Cloud Fraction from Cloud Top/Base



- CCCM CF > GEOPROF-LIDAR CF when |lat| > 40°, and 1 km < z < 8 km.
- GEOPROF-LIDAR CF < CCCM CF when |lat| < 30° and z < 1 km.
- CF difference is often up to 0.05.

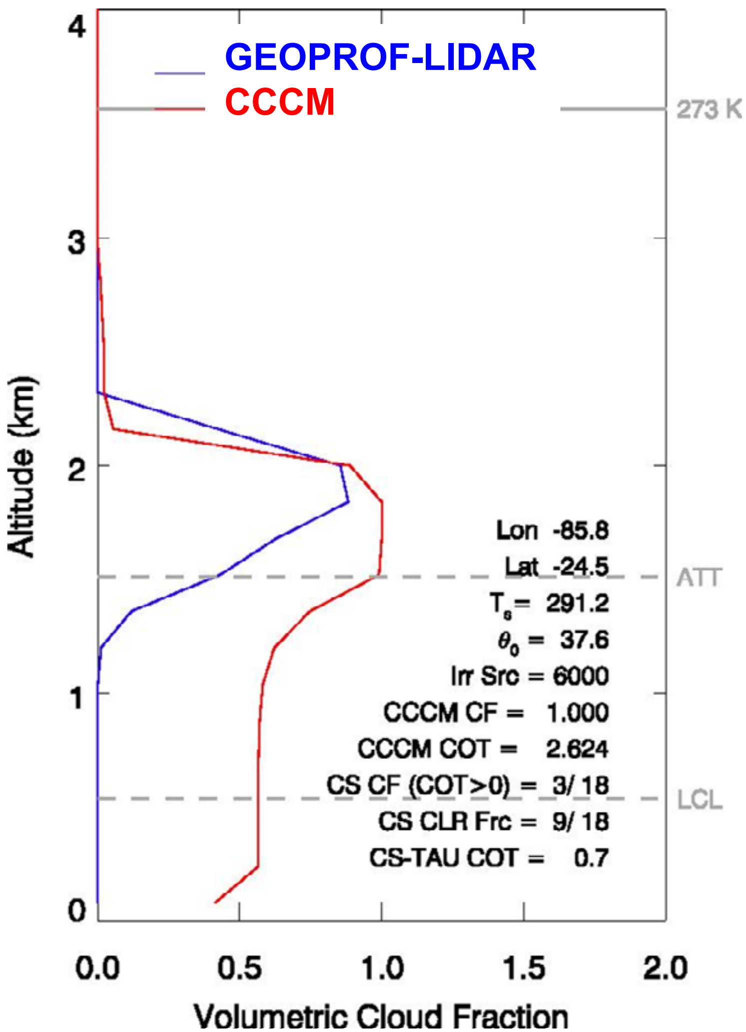
Multi-Layered in CCCM but Single-Layered in GEO-LIDAR

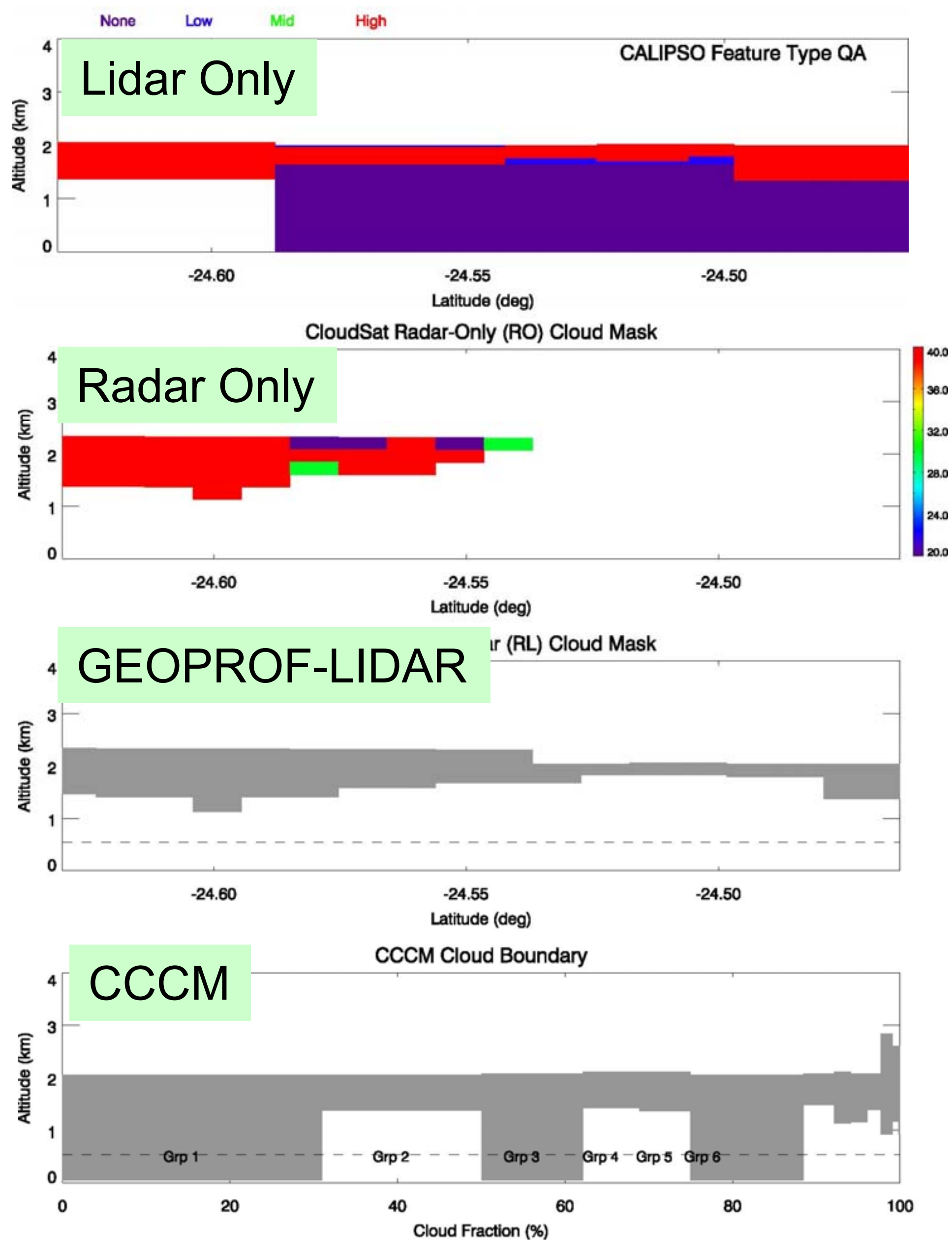




There are some vertical bins that Lidar reports clear but Radar reports cloudy → Different treatment of this region

Low-level Clouds Only Shown in CCCM

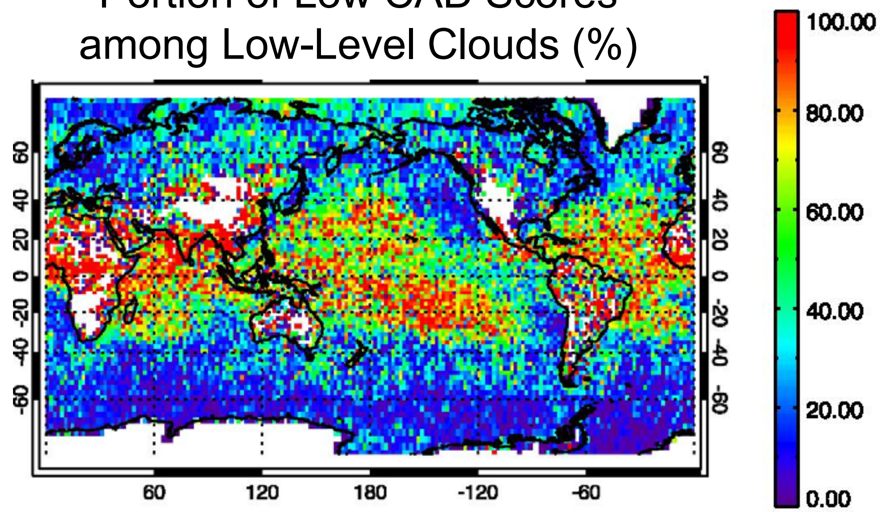




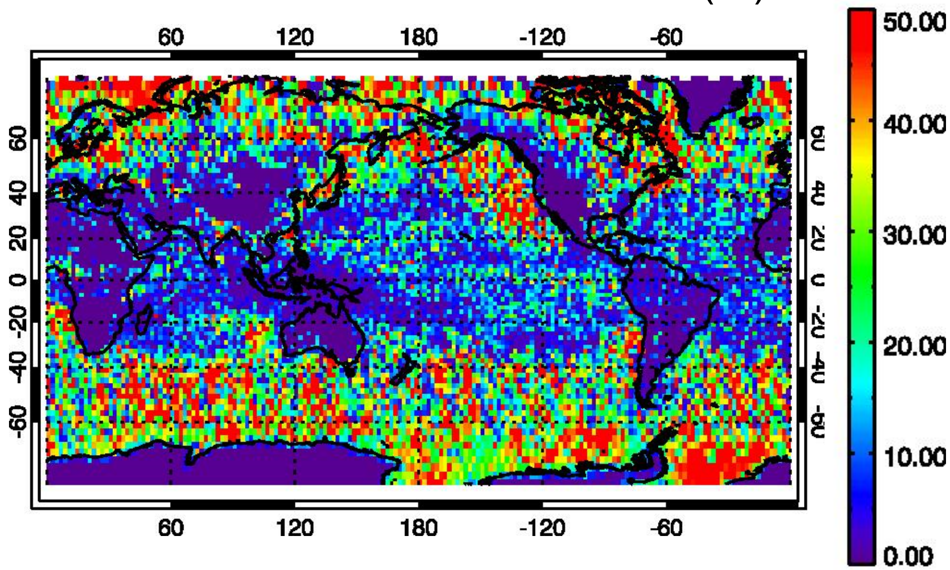
There are some vertical bins that Lidar reports cloudy, but with low Cloud-Aerosol-Discrimination (CAD) score.

Occurrence of Low-Level (0-1 km) Clouds with Low CAD Scores Observed by Lidar (JAN 2011)

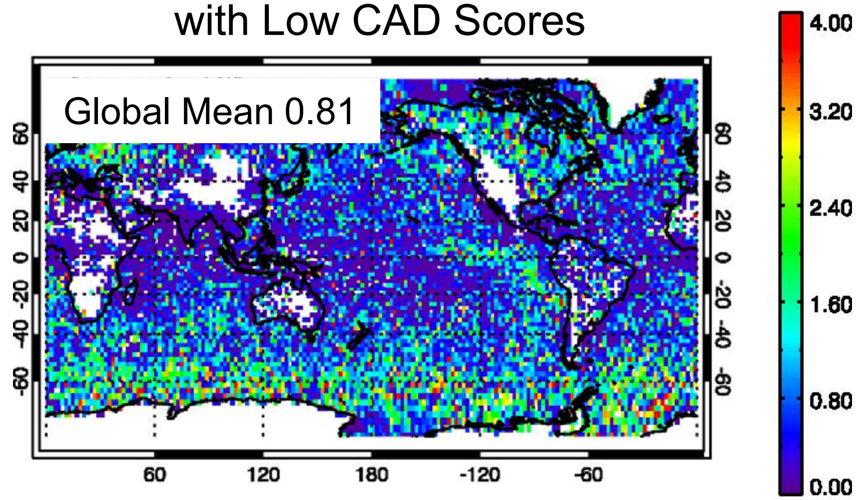
Portion of Low CAD Scores among Low-Level Clouds (%)



Occurrence of Low-Level Clouds (%)



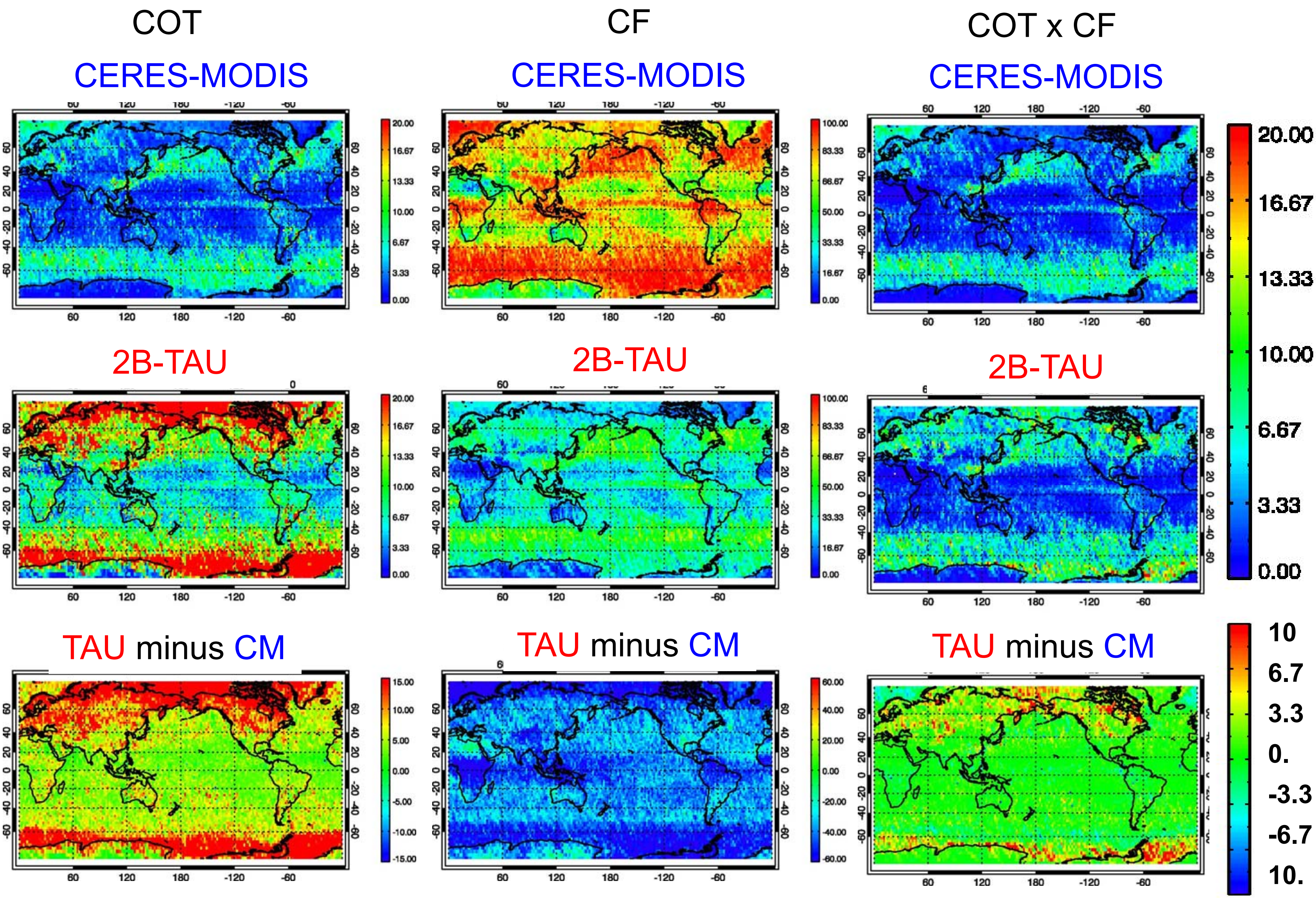
COT for Clouds with Low CAD Scores



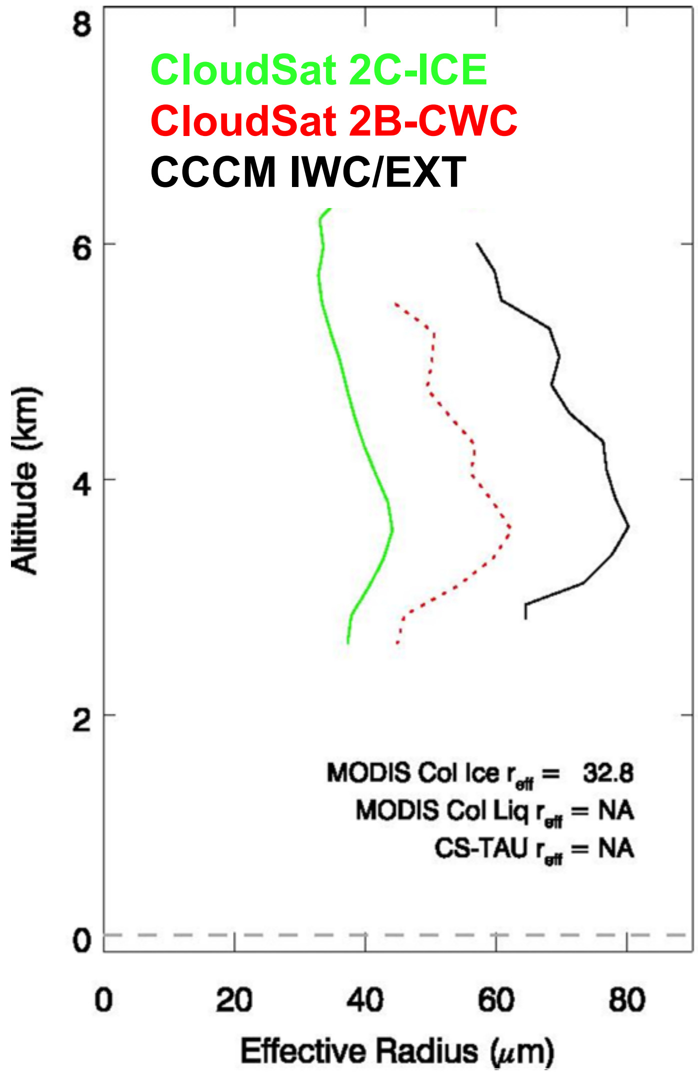
Radiative Impact of Low-CAD-Score Clouds may be small.

CERES-MODIS COT: Used for normalizing extinction profiles for CCCM Flux

CloudSat 2B-TAU COT: Used for normalizing extinction profiles for FLXHR-LIDAR



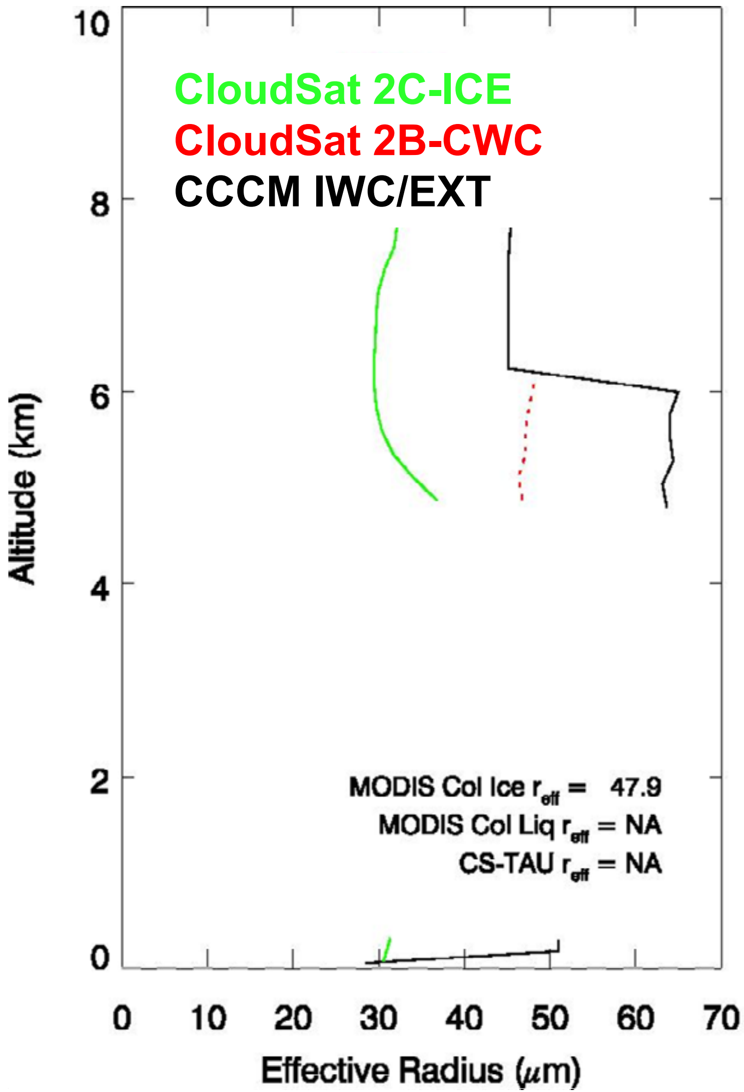
Current Issue of CCCM Algorithm I



- CCCM combines effective radius from Radar only algorithm (2B-CWC) and MODIS algorithm. Comparison with in-situ measurement, or with 2C-ICE shows that ice particle size in 2B-CWC may have large biases (Deng et al, 2013).
- CCCM uses area-volume relationship of nonspherical particle, in order to get IWC from 2B-CWC r_{eff}. This relation artificially increases IWC, and further IWC/EXT ratio (size information in RTM).

  → Being fixed for the next version.

Current Issue of CCCM Algorithm II

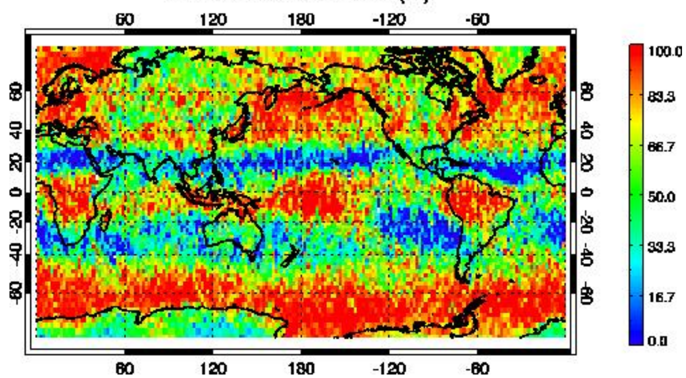


- CCCM brings effective radius from Radar only algorithm (2B-CWC). When 2B-CWC r_{eff} is not available (usually occurred in lidar-only cloud layer), MODIS r_{eff} is used, often showing discontinuity of size profile, depending on the source of particle size information.

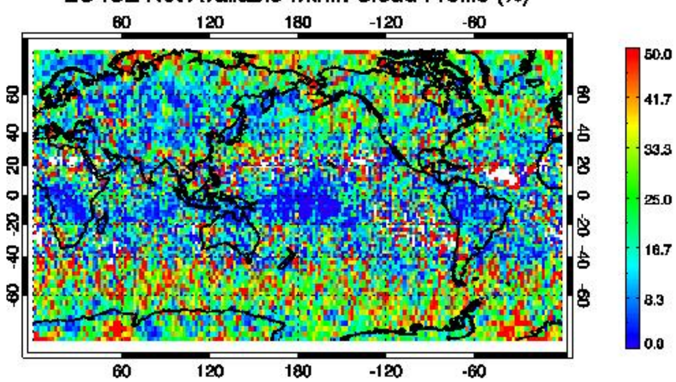
Availability of 2C-ICE Profiles

Clouds (T ≤ 273 K)

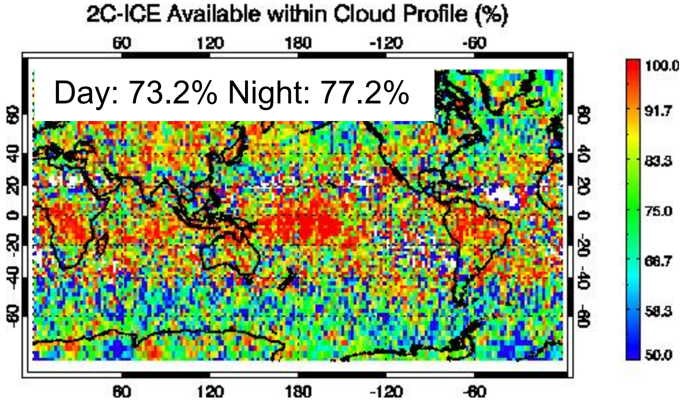
Occurence of Clouds (%)



2C-ICE Not Available within Cloud Profile (%)

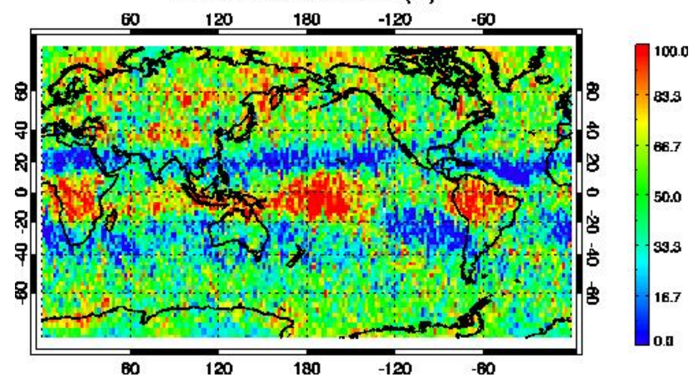


2C-ICE Available within Cloud Profile (%)

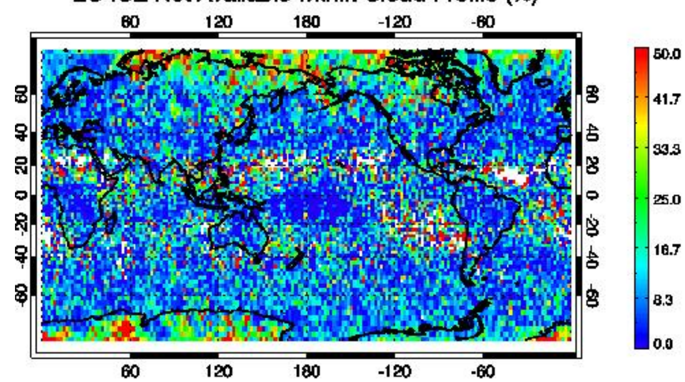


Clouds (T ≤ 253 K)

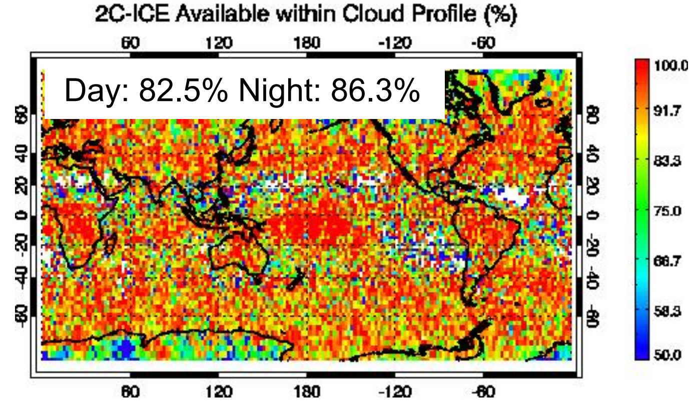
Occurence of Clouds (%)



2C-ICE Not Available within Cloud Profile (%)



2C-ICE Available within Cloud Profile (%)



Cloud Radiative Effects

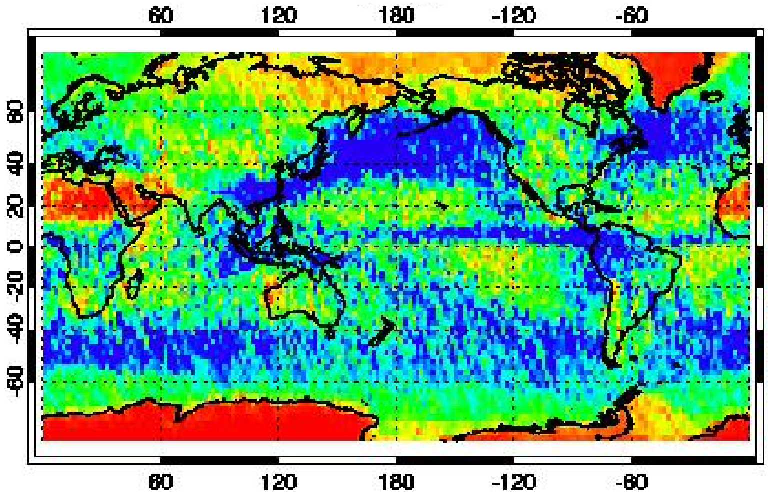
TOA Outgoing	CLR minus ALL
Absorption by Atmosphere	ALL minus CLR
SFC Incoming	ALL minus CLR

\+ Warming − Cooling by Clouds

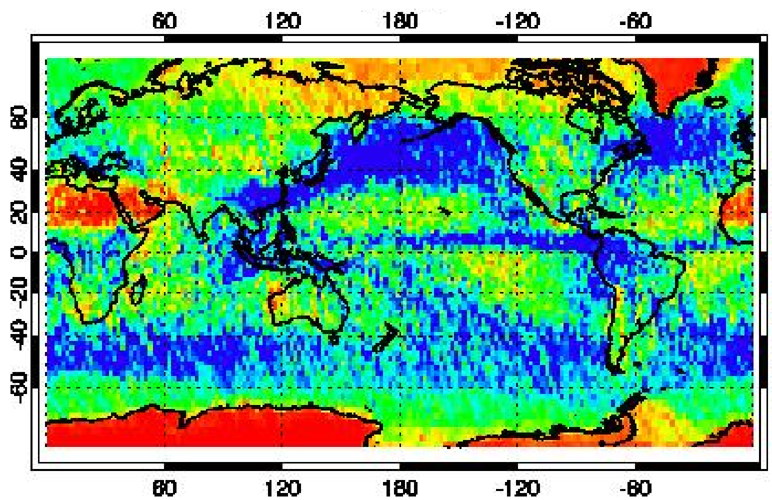
CLR − ALL SW TOAUP (CRE)

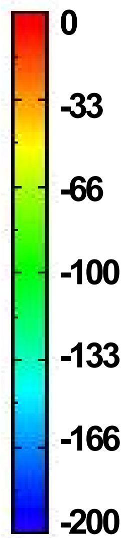
− is Earth Cooling by Cloud Reflection

CCCM



FLXHR-LIDAR

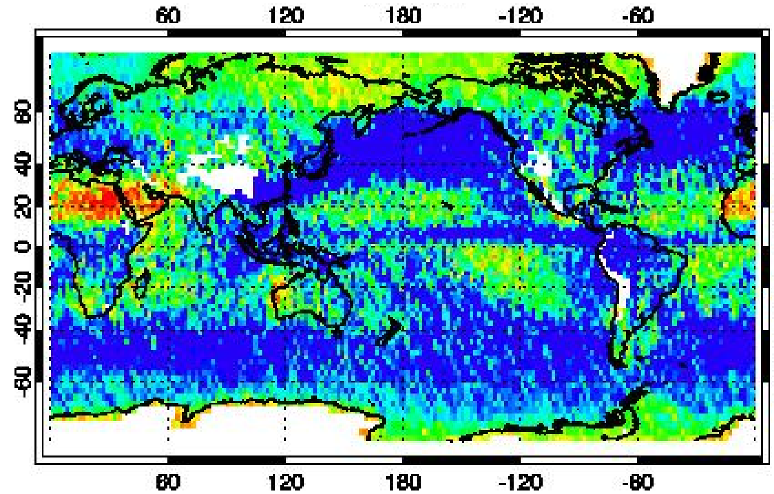




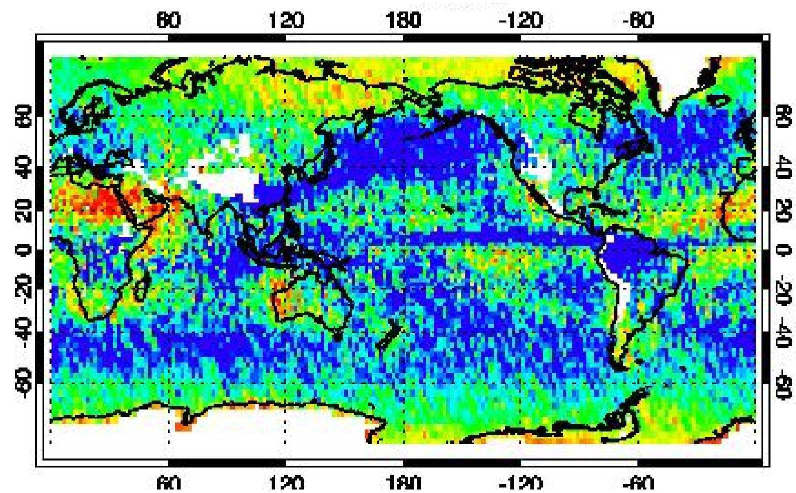
ALL − CLR SW SFCDN (CRE)

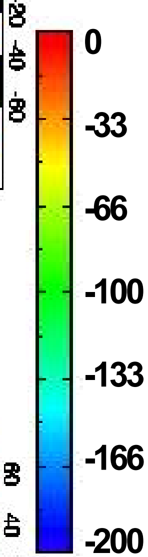
− is SFC Cooling by Cloud Extinction

CCCM



FLXHR-LIDAR

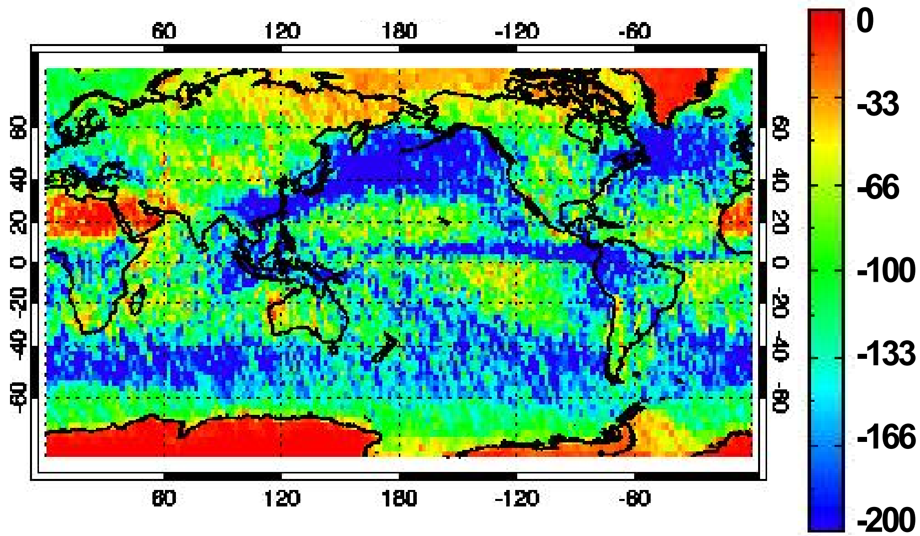




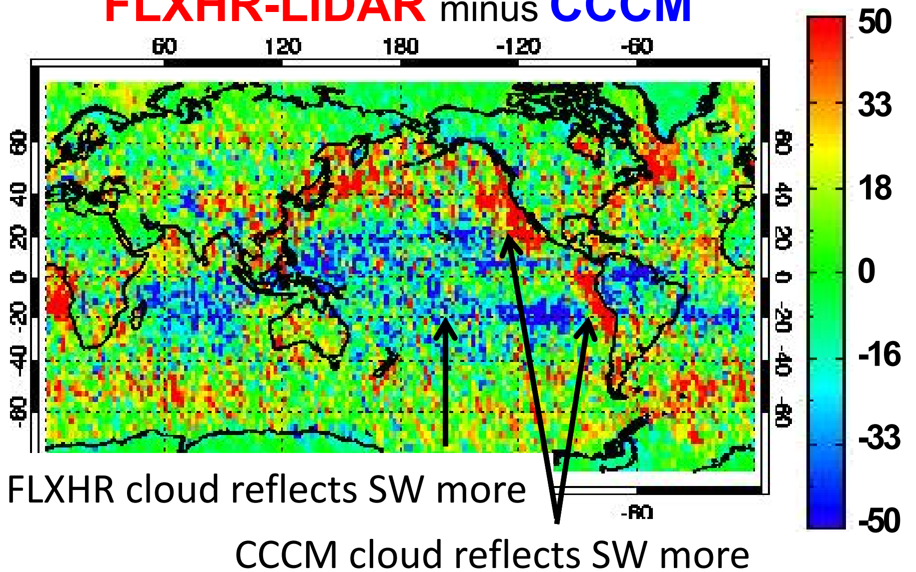
CLR − ALL SW TOAUP (CRE)

− is Earth Cooling by Cloud Reflection

CCCM



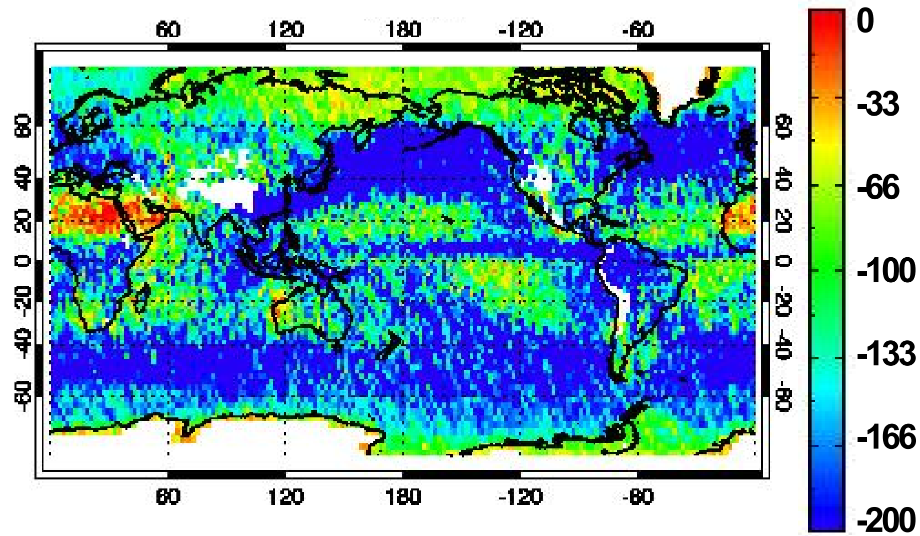
FLXHR-LIDAR minus CCCM



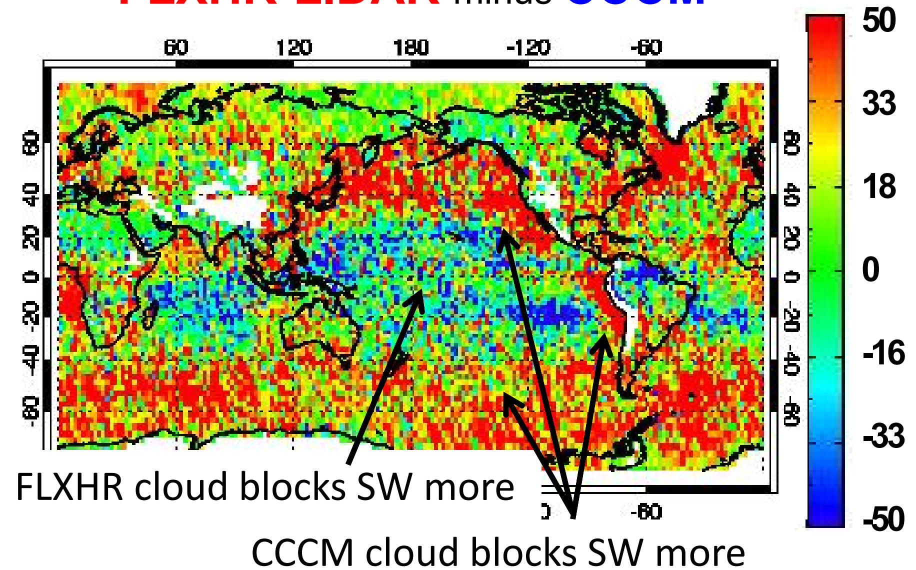
ALL − CLR SW SFCDN (CRE)

− is SFC Cooling by Cloud Extinction

CCCM

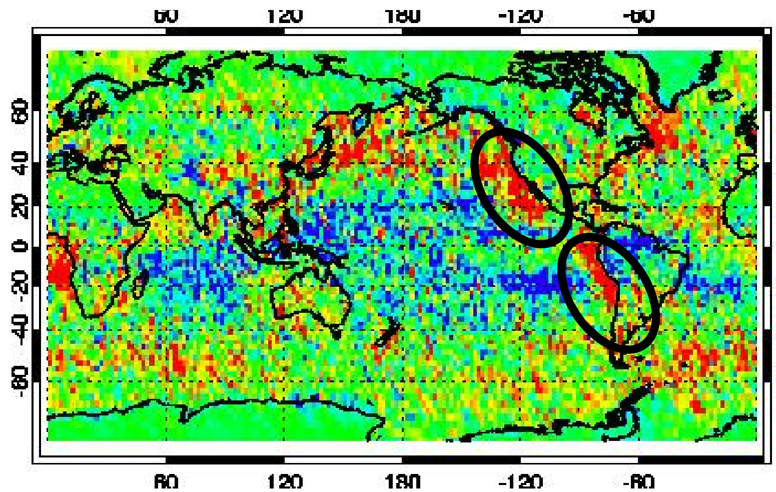


FLXHR-LIDAR minus CCCM

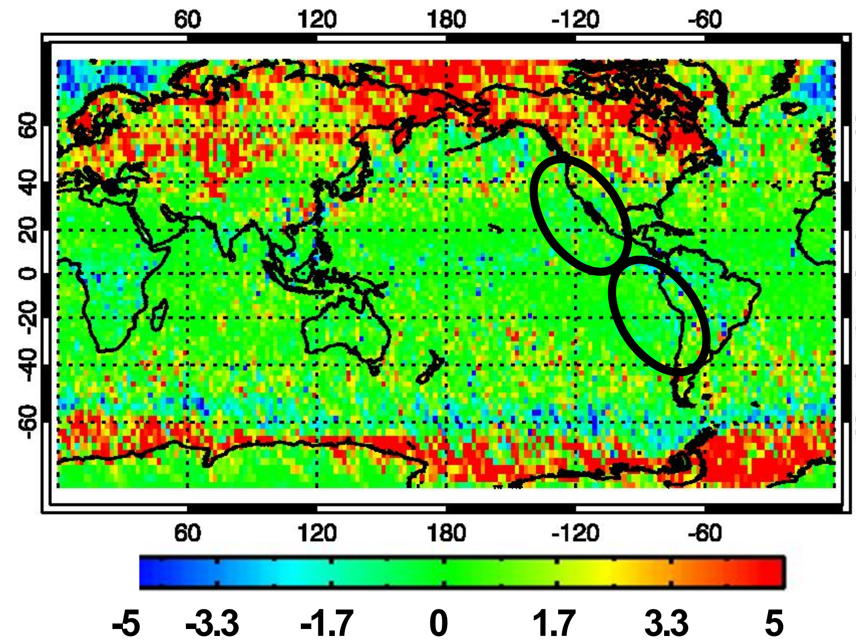


CRE Diff versus COT Diff

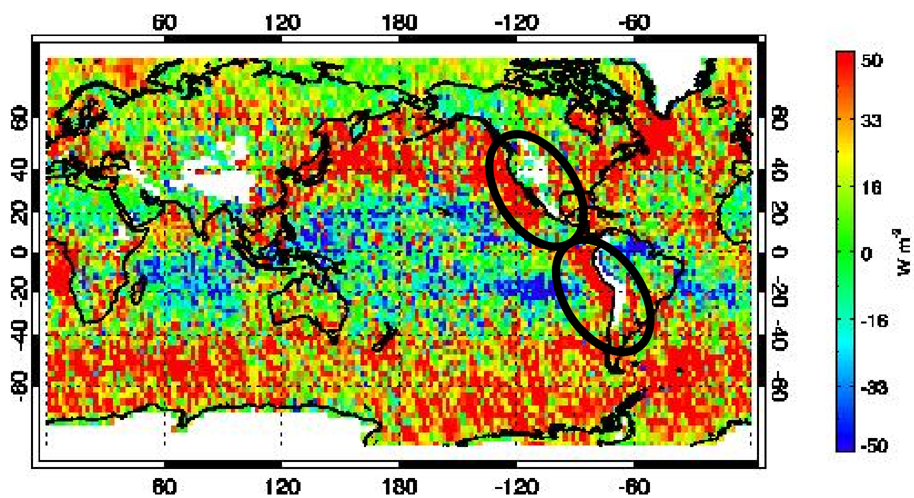
FLXHR-LIDAR minus CCCM
SW TOA CRE (CLR − ALL)



CS-TAU minus CCCM

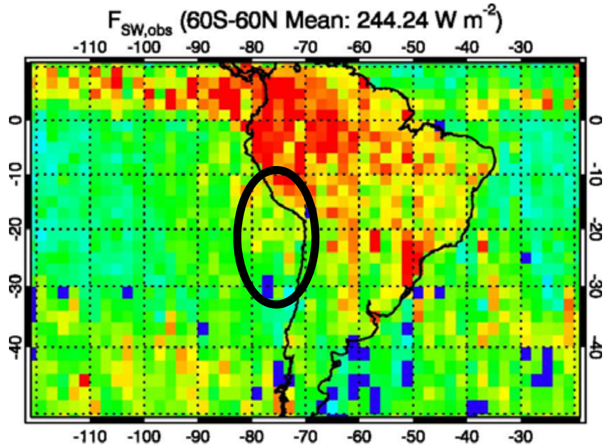


FLXHR-LIDAR minus CCCM
SW SFC CRE (ALL − CLR)



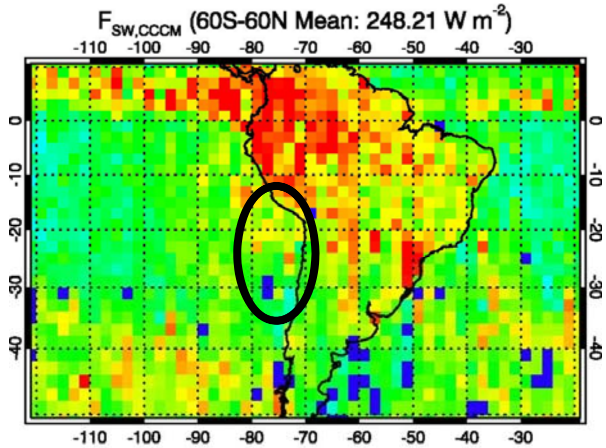
COT differences do not explain SW CRE differences.

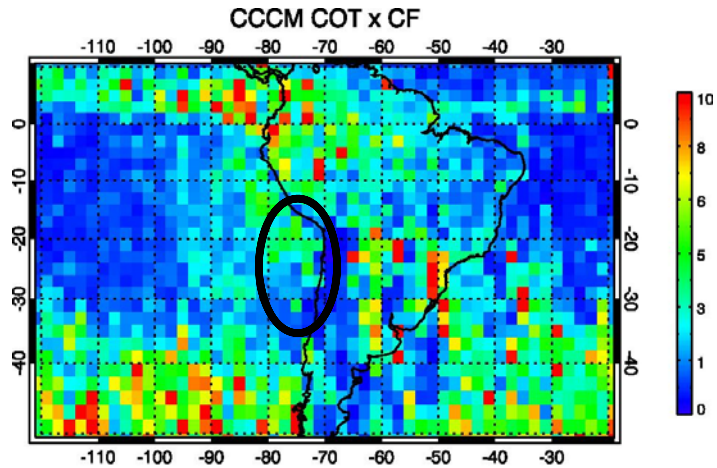
CERES OBS



We expect FLXHR-LIDAR does not use CS-TAU COT for Eastern Pacific Coast Region.

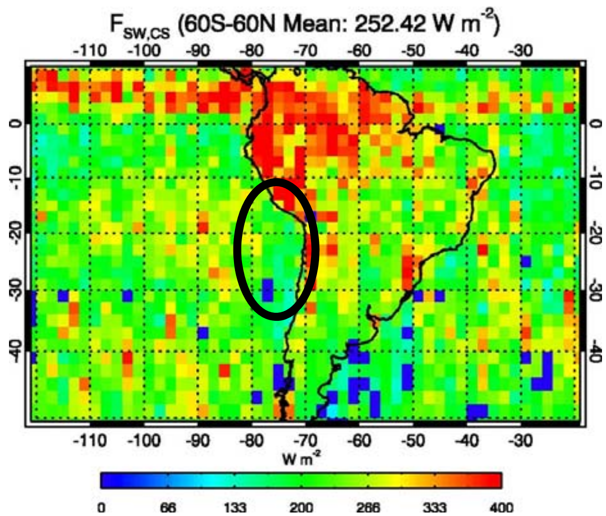
CCCM SWTOA

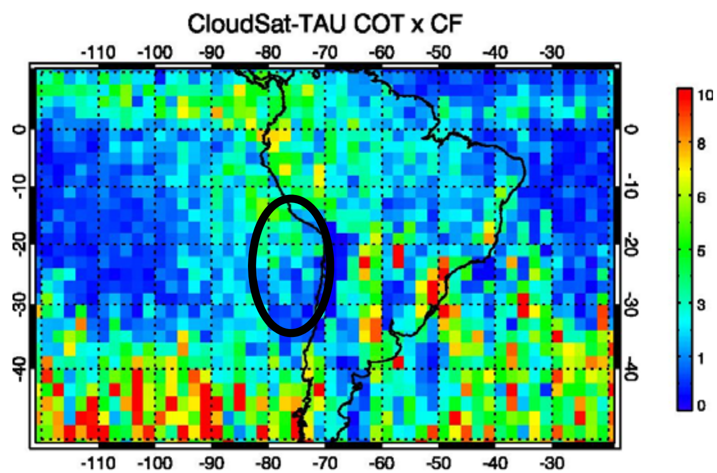




CCCM COT

FLXHR- LIDAR SWTOA



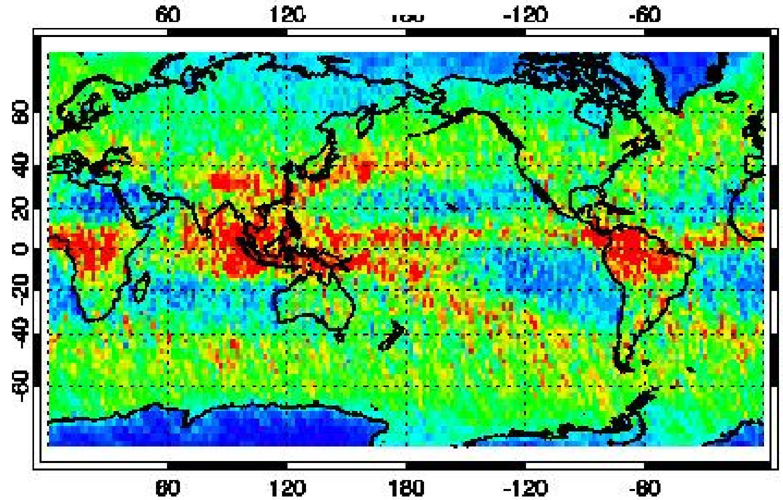


CS-TAU COT

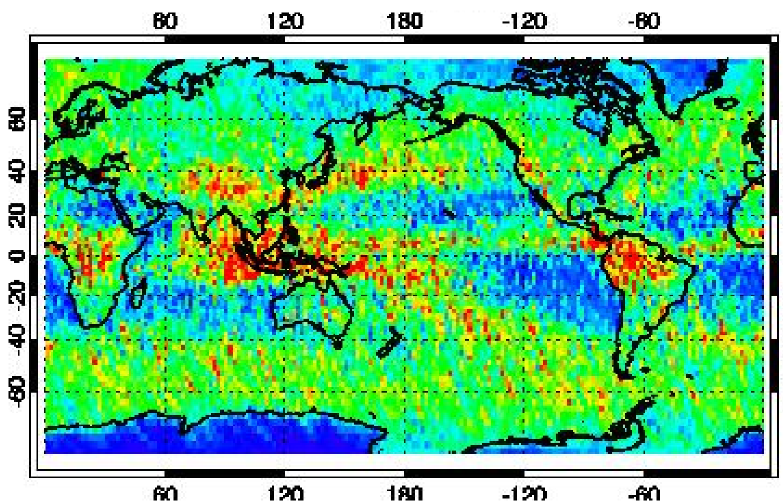
CLR − ALL LW TOAUP (CRE)

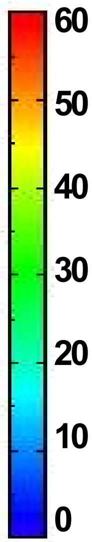
+ is Earth Warming by Cloud IR Trapping

CCCM



FLXHR-LIDAR

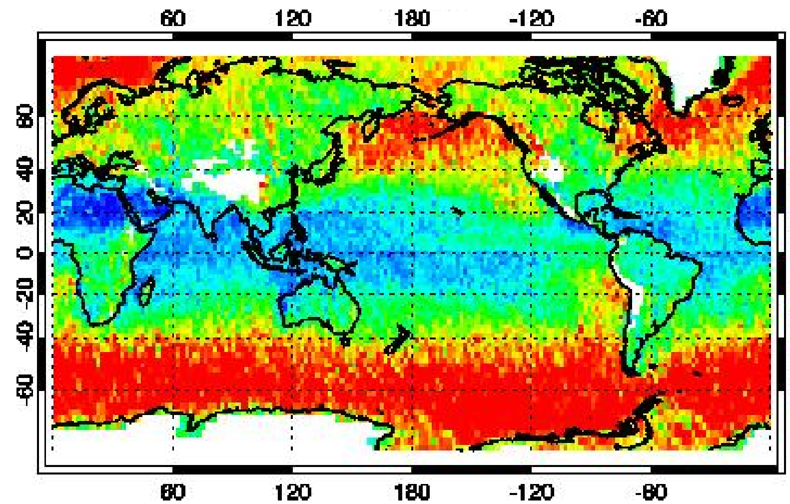




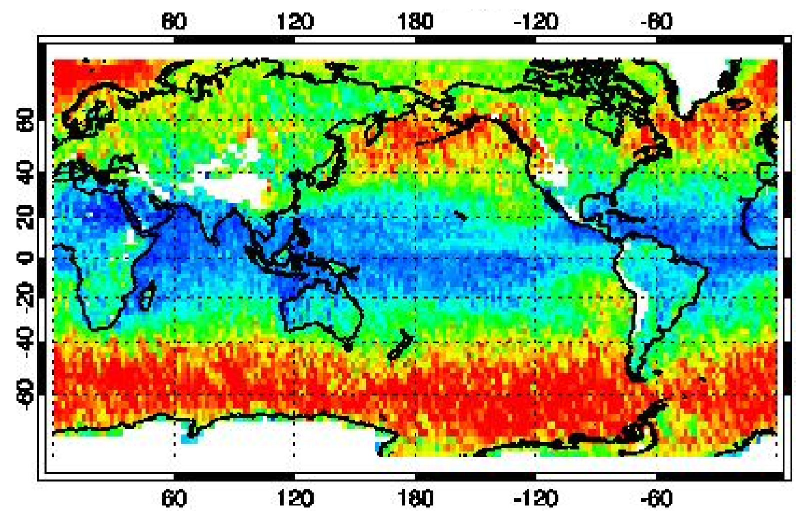
ALL − CLR LW SFCDN (CRE)

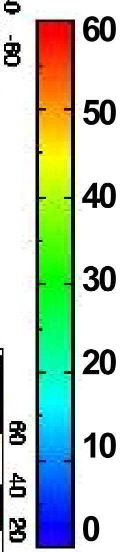
+ is SFC Warming by Cloud Emission

CCCM



FLXHR-LIDAR

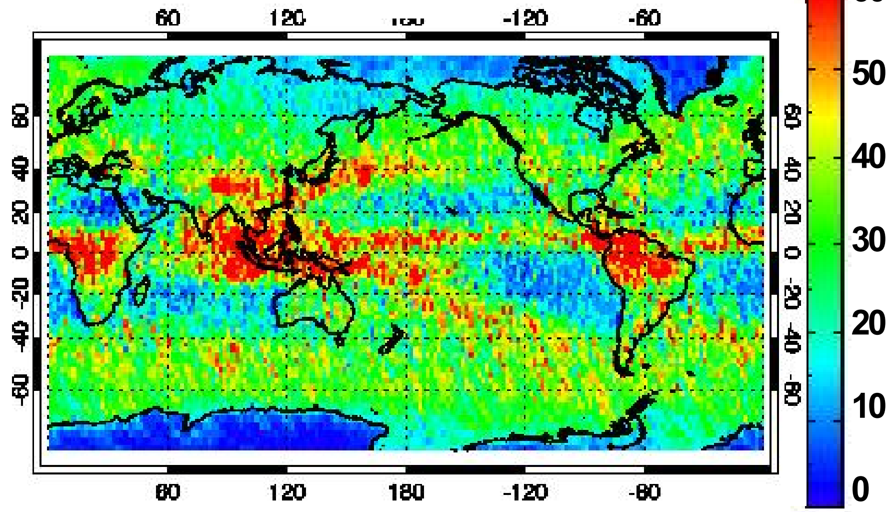




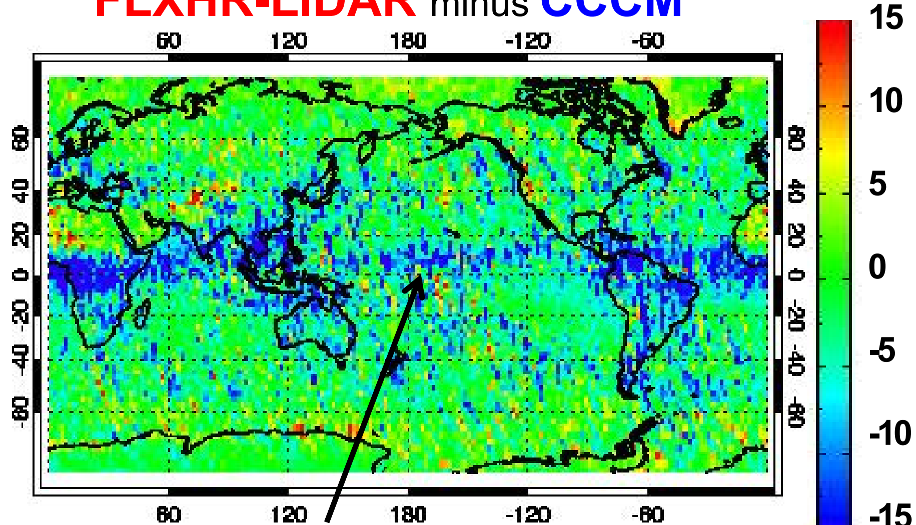
CLR − ALL LW TOAUP (CRE)

+ is Earth Warming by Cloud IR Trapping

CCCM



FLXHR-LIDAR minus **CCCM**

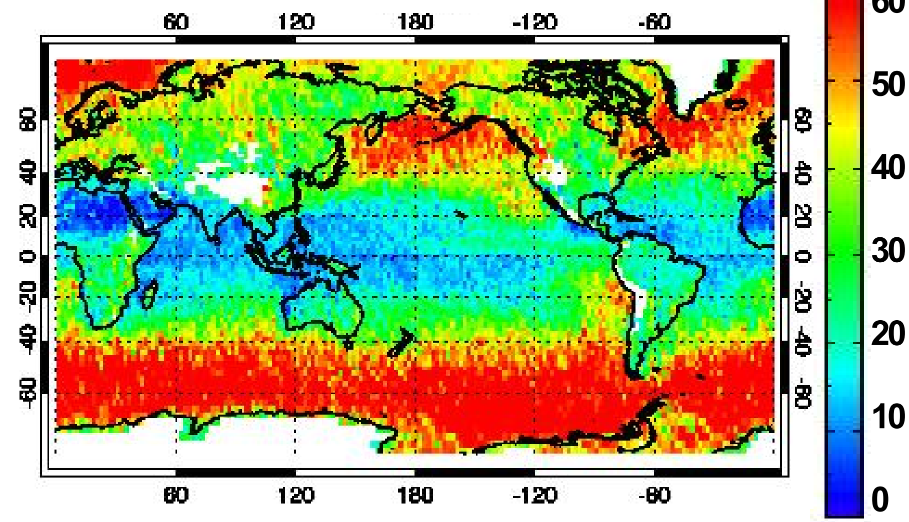


CCCM cloud traps LW more (larger ice particle)

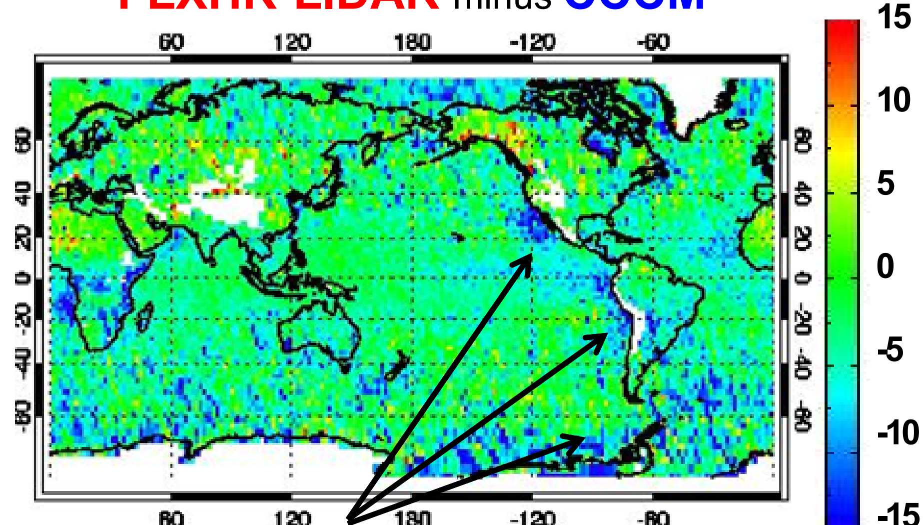
ALL − CLR LW SFCDN (CRE)

+ is SFC Warming by Cloud Emission

CCCM



FLXHR-LIDAR minus **CCCM**

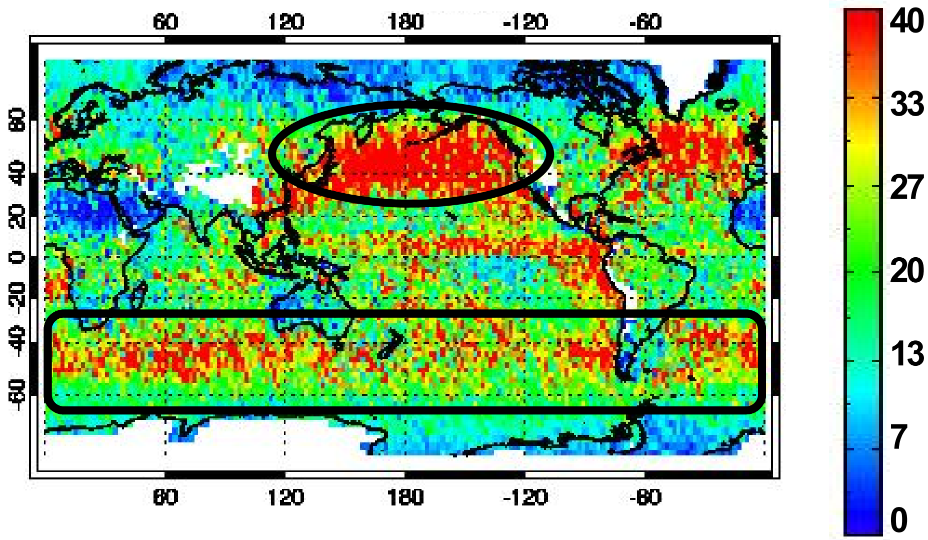


CCCM low cloud emits LW more than FLXHR (COT)

ALL − CLR SW ABS

+ is Cloud SW Absorption

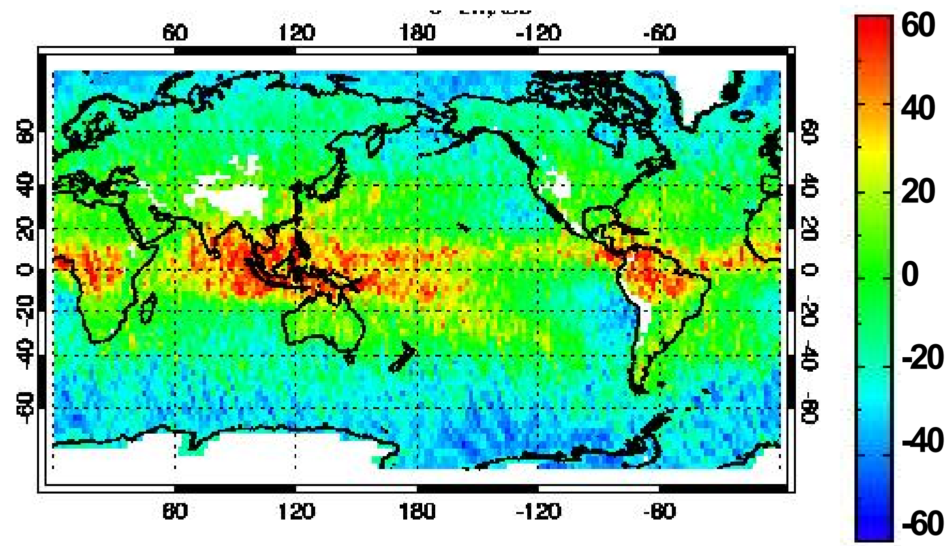
CCCM



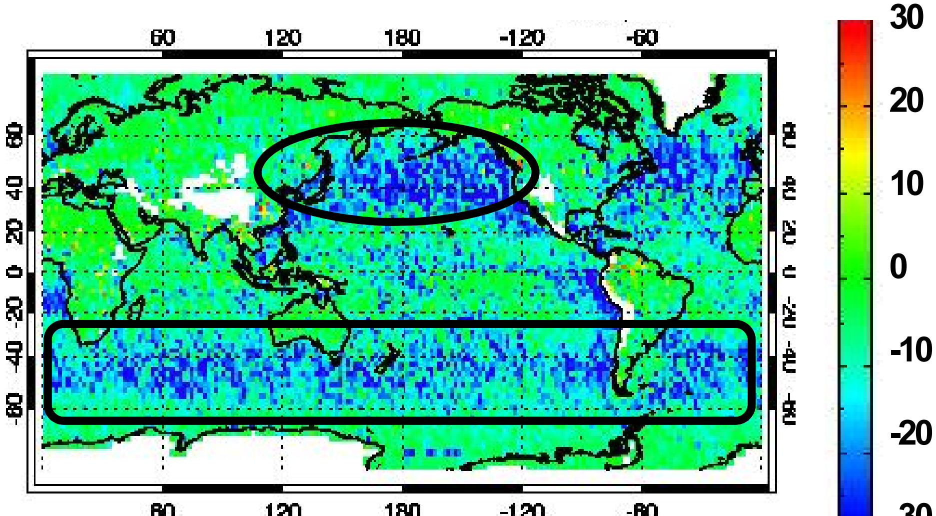
ALL − CLR LW ABS

+ and − are IR Trapping and Emission by Cloud

CCCM

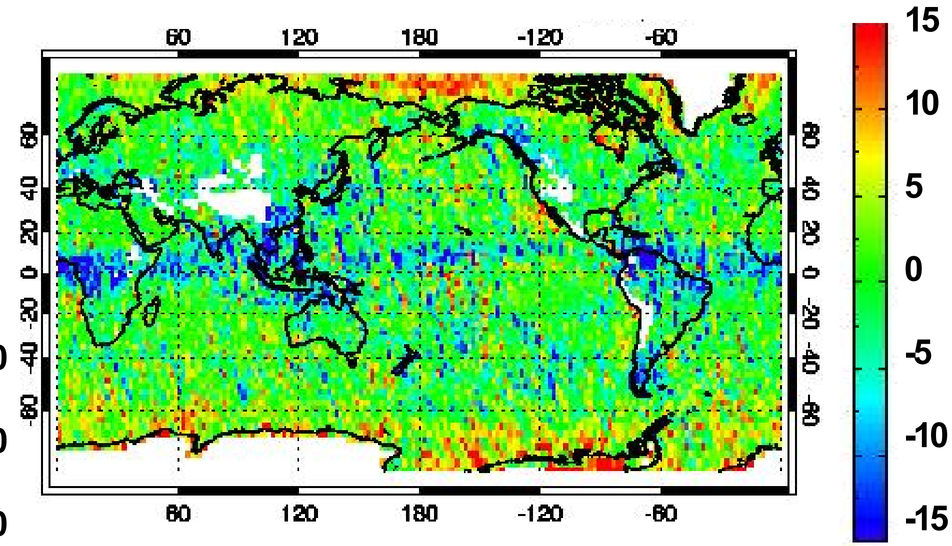


FLXHR-LIDAR minus **CCCM**



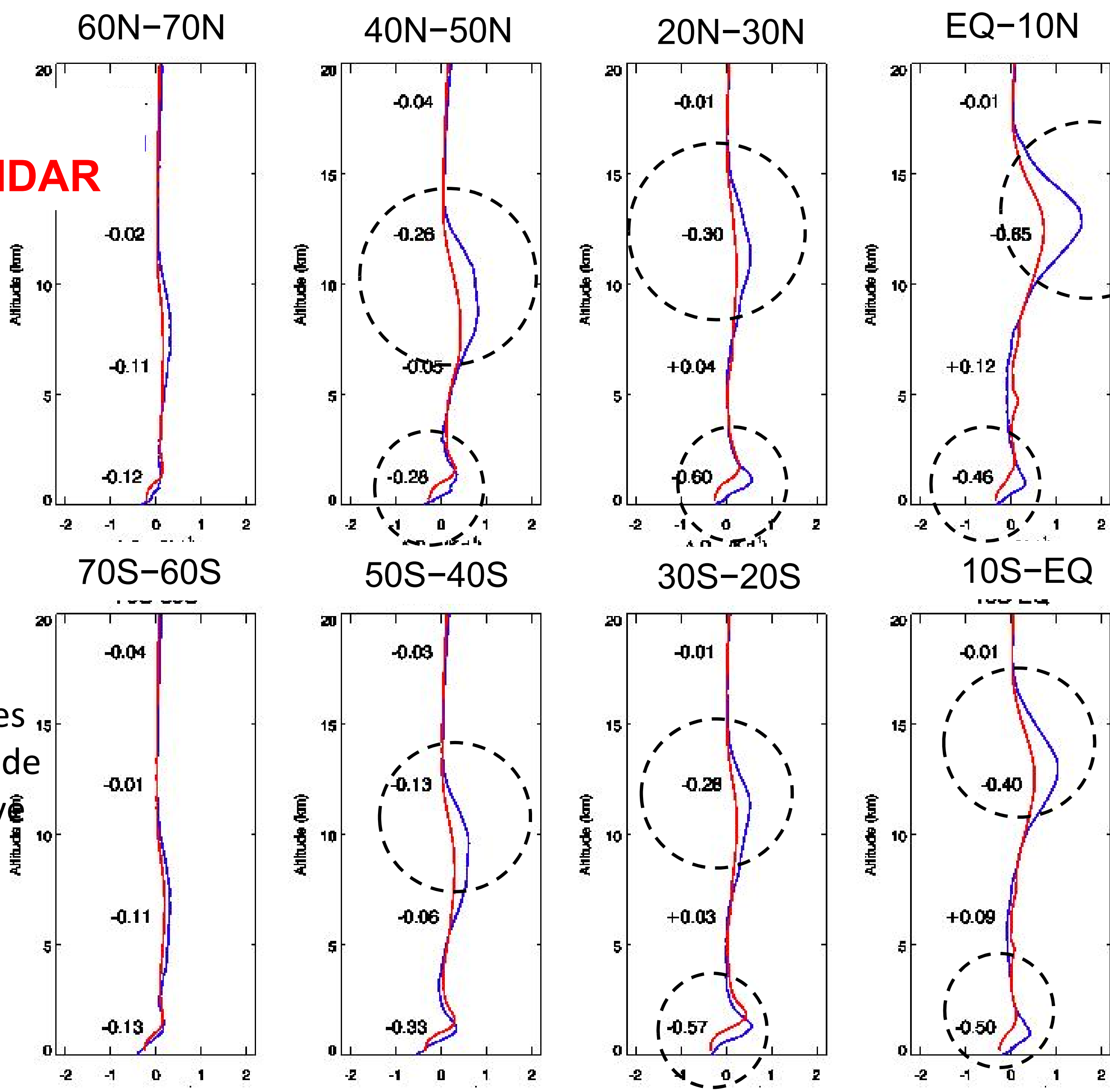
CCCM cloud absorbs SW more than FLXHR

FLXHR-LIDAR minus **CCCM**



ALL – CLR SW HR

CCCM
FLXHR-LIDAR



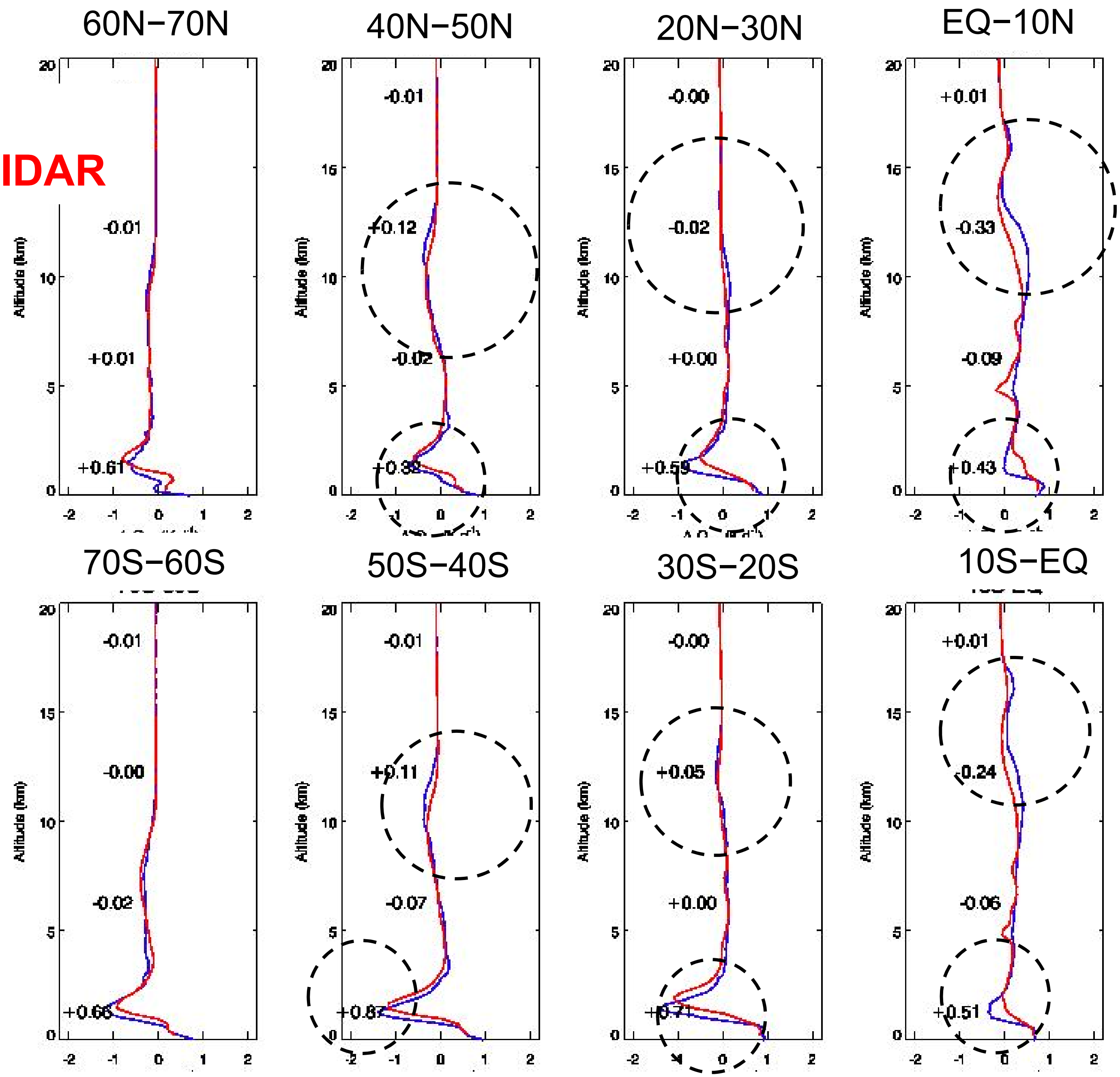
CCCM > FLXHR-LIDAR

CF differences in high latitude does not have noticeable radiative effects

COT difference is very small for tropical region.

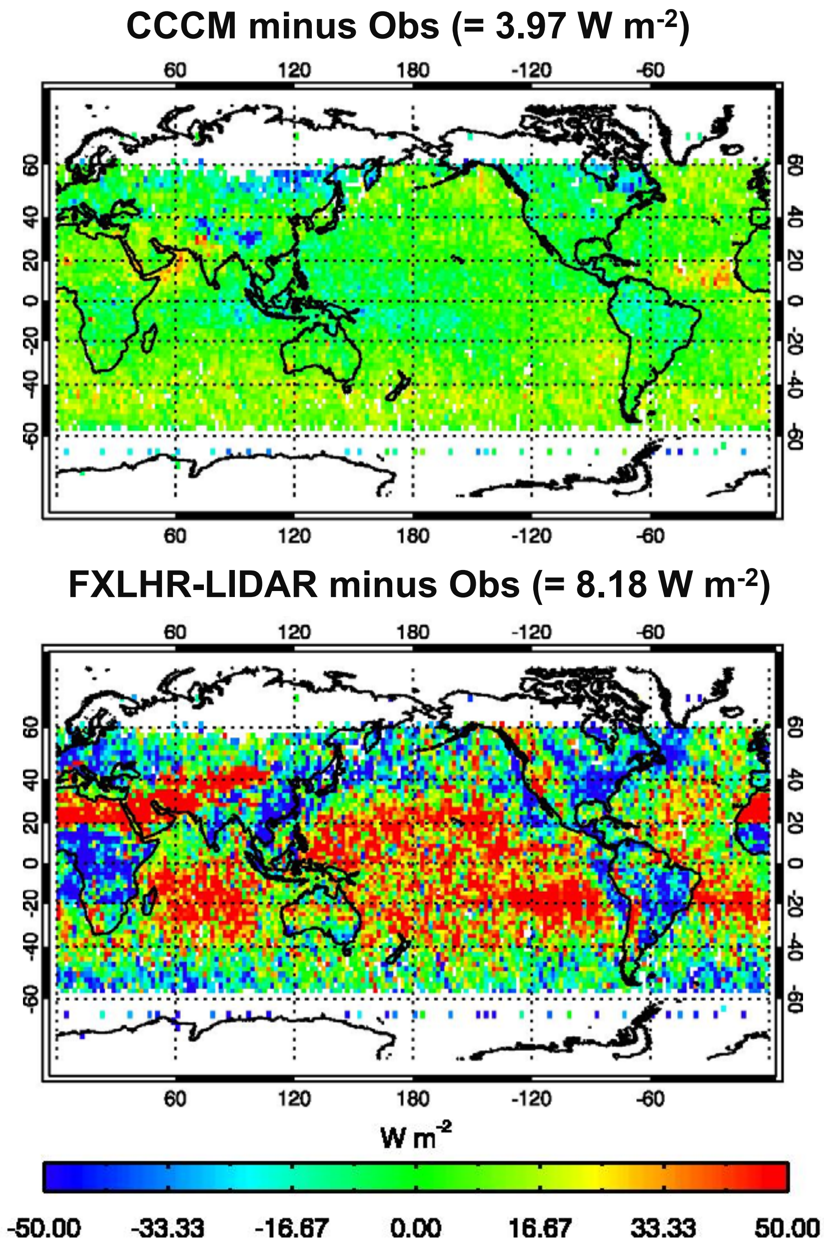
ALL – CLR LW HR

CCCM
FLXHR-LIDAR



|CCCM| > |FLXHR-LIDAR|

SW Radiative Closure at TOA (Using CERES Observation)



CCCM extinction coeff profile is normalized using MODIS COT and $g(r_{eff})$:

$$\tau_M\{1-g(r_M)\} = \sum_{iz=1}^{nz} \tau_{CC}\{1-g(r_{CC})\}$$

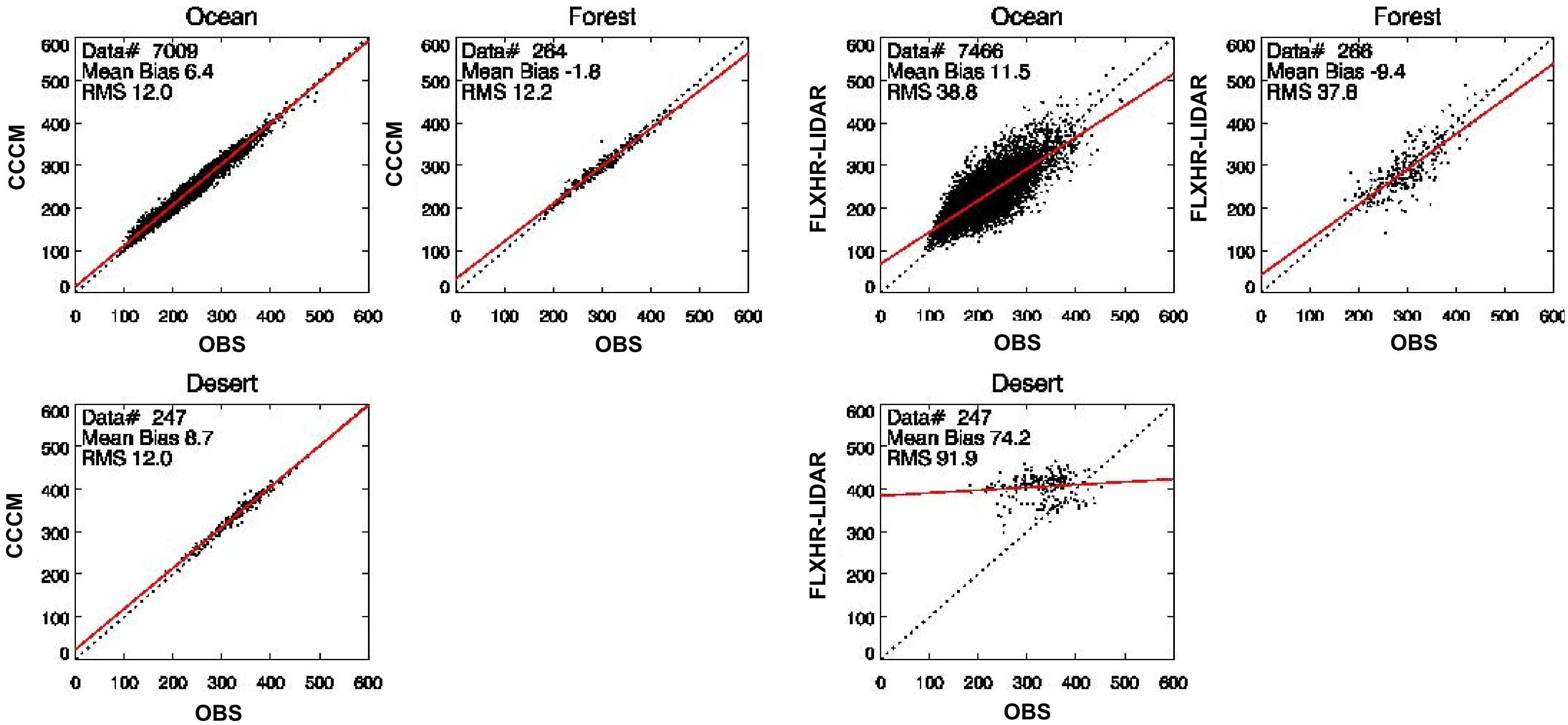
Once MODIS-derived parameters are used to normalize cloud extinction profile, it reproduce TOA flux well!

Note: High-Latitude (> 60°) is excluded in the comparison because of frequent missing of flux computation (different sampling issues)

Comparison with CERES SW TOA Measurements (2°-Gridded)

4month data

CCCM FLXHR-LIDAR



- Even though CCCM ice particle size, it produces TOA SW flux since extinction profile is normalized by MODIS cloud optical depth anyway.
- FLXHR-LIDAR TOA fluxes show deviations from the CERES measurements, caused by surface albedo assumption (particularly desert area).

Summary of Cloud Radiative Effects in CCCM and FLXHR-LIDAR

1. Low-level clouds in Eastern Pacific Coast show larger SW reflection and SW/LW absorption in CCCM, compared to FLXHR-LIDAR. → "Larger CCCM COT"
2. Sub-tropical low-level marine clouds show similar SW reflection but larger SW absorption in CCCM, compared to FLXHR-LIDAR.
   → "Larger CCCM r_{eff}"
3. Tropical marine clouds in subsidence region show larger SW reflection in FLXHR-LIDAR, compared to CCCM. → Larger FLXHR COT
4. Tropical deep convective region shows colder LW emission at TOA and larger LW absorption. SW difference is not noticeable.
   → Larger CCCM r_{eff} but with small occurrence

Summary

- Eastern Pacific low-level clouds show larger reflection and absorption in CCCM products, in comparison to FLXHR-LIDAR. Moreover, subtropical low clouds show similar reflection, but larger absorption in CCCM.
- CCCM and GEOPROF-LIDAR show generally well agreed cloud fraction profiles, and the differences would not produce significant radiative impacts. High-latitude mid-level clouds show differences, probably related to precipitation. Tropical low-level marine clouds are related to low CAD score.
- Two MODIS-derived COTs (CERES-MODIS and CS-TAU, respectively) agree well, when taking into account cloud fraction (COT x CF).
- Eastern Pacific low-level clouds have similar MODIS COT in two products, but FLXHR-LIDAR seems to have clear sky in that region.
- CCCM uses larger ice cloud particle sizes than those provided in 2B-CWC, because of double size conversion. Moreover, merged cloud particle size profile often has sharp transition when different sources are used.
- CCCM TOA SW fluxes show good agreement with CERES observation. This shows importance of normalization of extinction profile by MODIS COT.
- FLXHR-LIDAR shows generally good agreement with CERES observation, but larger deviation from observation is found over desert than over ocean.

Summary

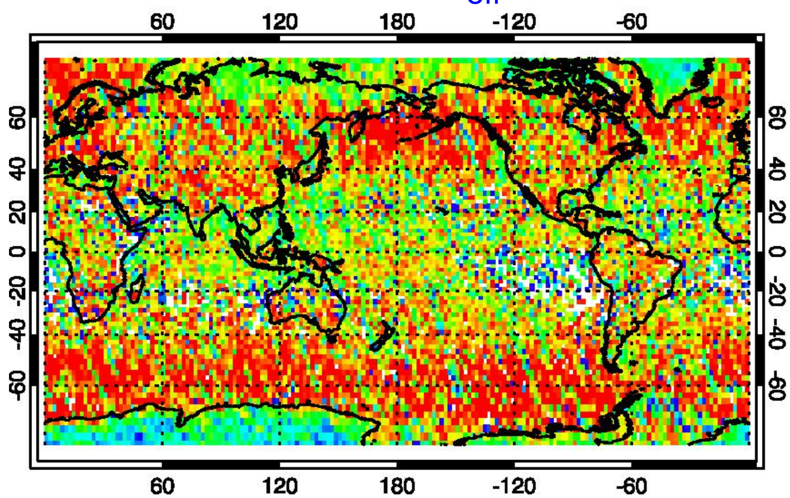
- High-latitude mid-level clouds have larger volumetric cloud fraction in 2B-GEOPROF-LIDAR than CCCM, which is related to precipitation. Moreover, CCCM has more frequent low-level clouds, which are related low CAD scores in CALIPSO cloud detection. The differences in two cloud fractions are up to 5%.
- Cloud optical thicknesses (COT) x CF in CERES-MODIS and 2B-TAU show comparable monthly mean distribution. These are used for normalizing extinction profiles from active sensors.
- Both CCCM and FLXHR-LIDAR composite effective radii from 2B-CWC and MODIS-derived effective radius for flux computation. However, CCCM ice effective radius is larger because of duplicated conversion between effective radius and geometric diameter.
- CCCM sub-tropical clouds more reflect and absorb SW than FLXHR-LIDAR clouds. FLXHR-LIDAR tropical marine clouds reflect more SW than CCCM, but SW absorption is similar. This suggests that effective radius of subtropical CCCM clouds have larger ice particles.
- From the case study, we have

Summary

1. We have found noticeable differences in cloud fraction between CCCM and GEOPROF-LIDAR products. The differences in marine low-level clouds are due to aerosol contamination, and the differences in high-latitude mid-level clouds may be related to precipitating clouds.
2. Compared to cloud fractions, optical properties such as particle sizes and extinction coefficient are more variable between CCCM and CloudSat-LIDAR products. Compared to 2B-CWC or 2C-ICE products, CCCM uses larger ice particle sizes, resulting in larger cloud absorption.
3. Cloud radiative effects (CREs) on SW heating rates (all sky minus clear sky) are much larger in CCCM products, in comparison to FLXHR-LIDAR products. For the similar cloud optical depths, CCCM shows much larger cloud absorption, suggesting larger ice particle sizes.
4. Despite of lager ice particle size, CCCM shows fairly good agreement of TOA flux with CERES measurements, due to normalization of cloud extinction by MODIS cloud optical depth. FLXHR-LIDAR shows more scattered patterns from measurements due to surface albedo problem.

Ice Column Particle Effective Radius

CCCM r_{eff}

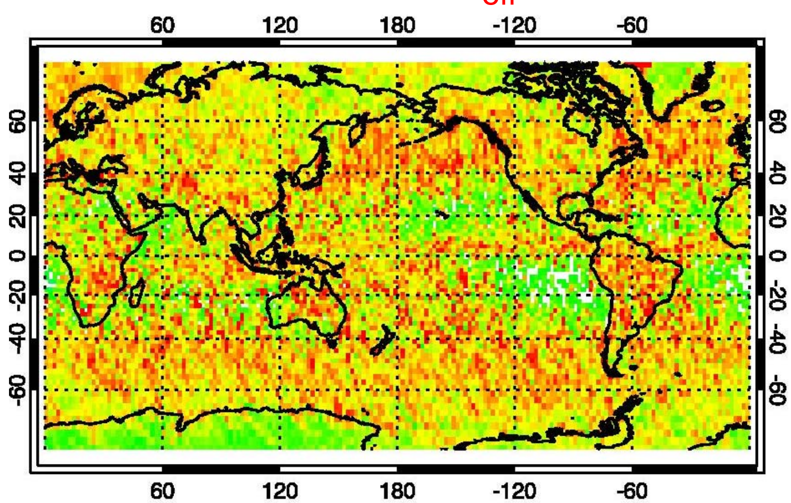


CCCM r_{eff}: Combination of CERES-MODIS r_{eff} and 2B-CWC r_{eff}

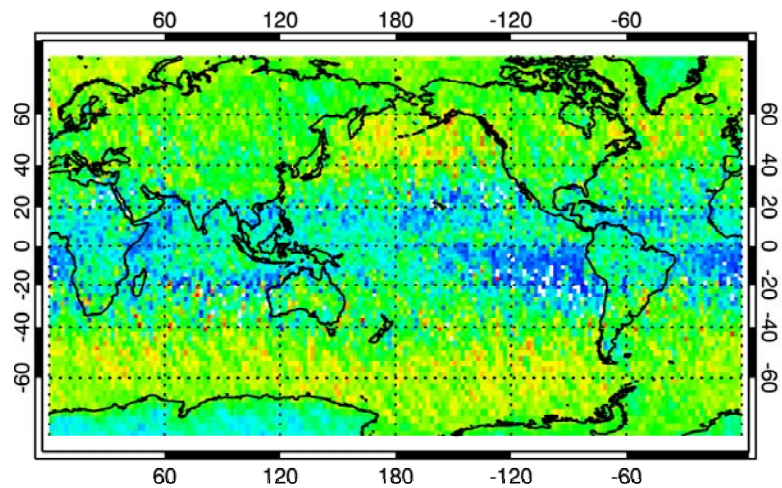
2B-CWC r_{eff}: Radar-Only (CloudSat-Only) products

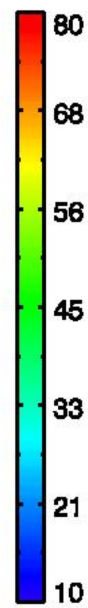
2C-ICE r_{eff}: Radar-Lidar combined products for ice

2B-CWC r_{eff}



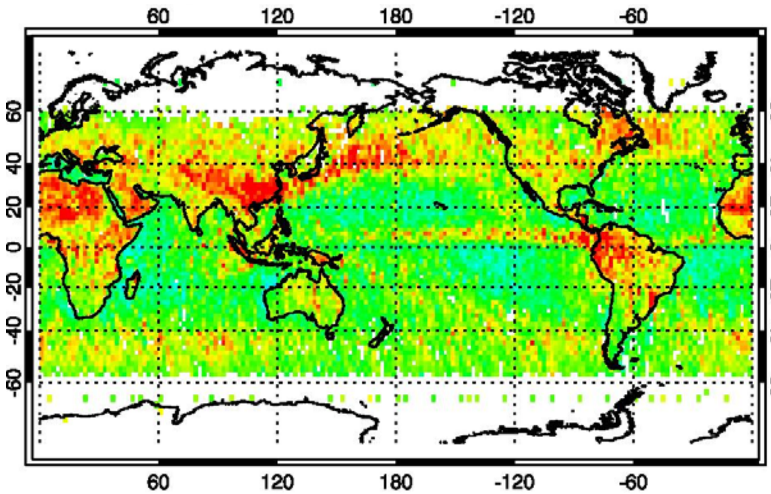
2C-ICE r_{eff}



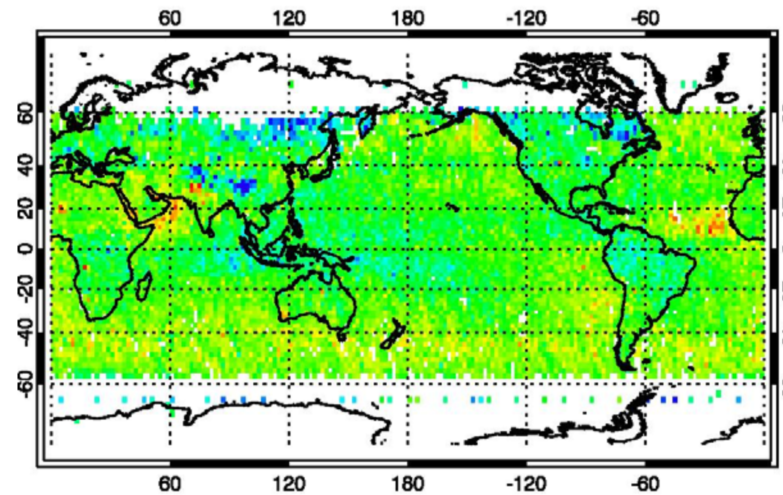


SW Radiative Closure at TOA (Using CERES Observation)

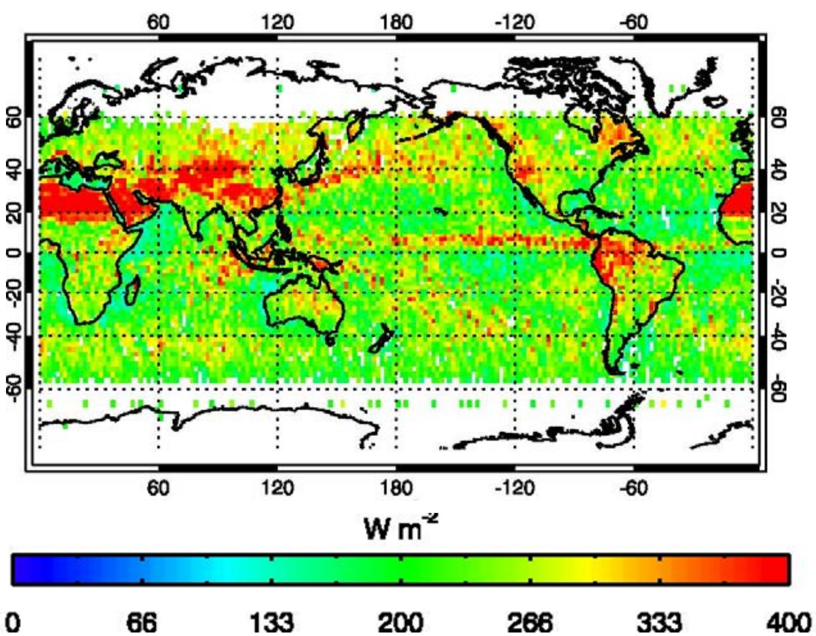
CCCM



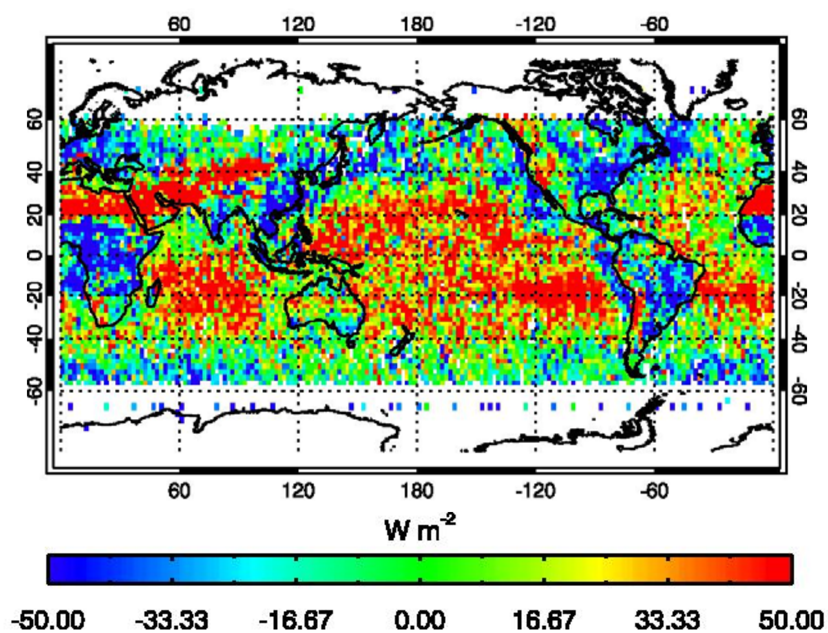
CCCM minus Obs (= 3.97 W m^{-2})



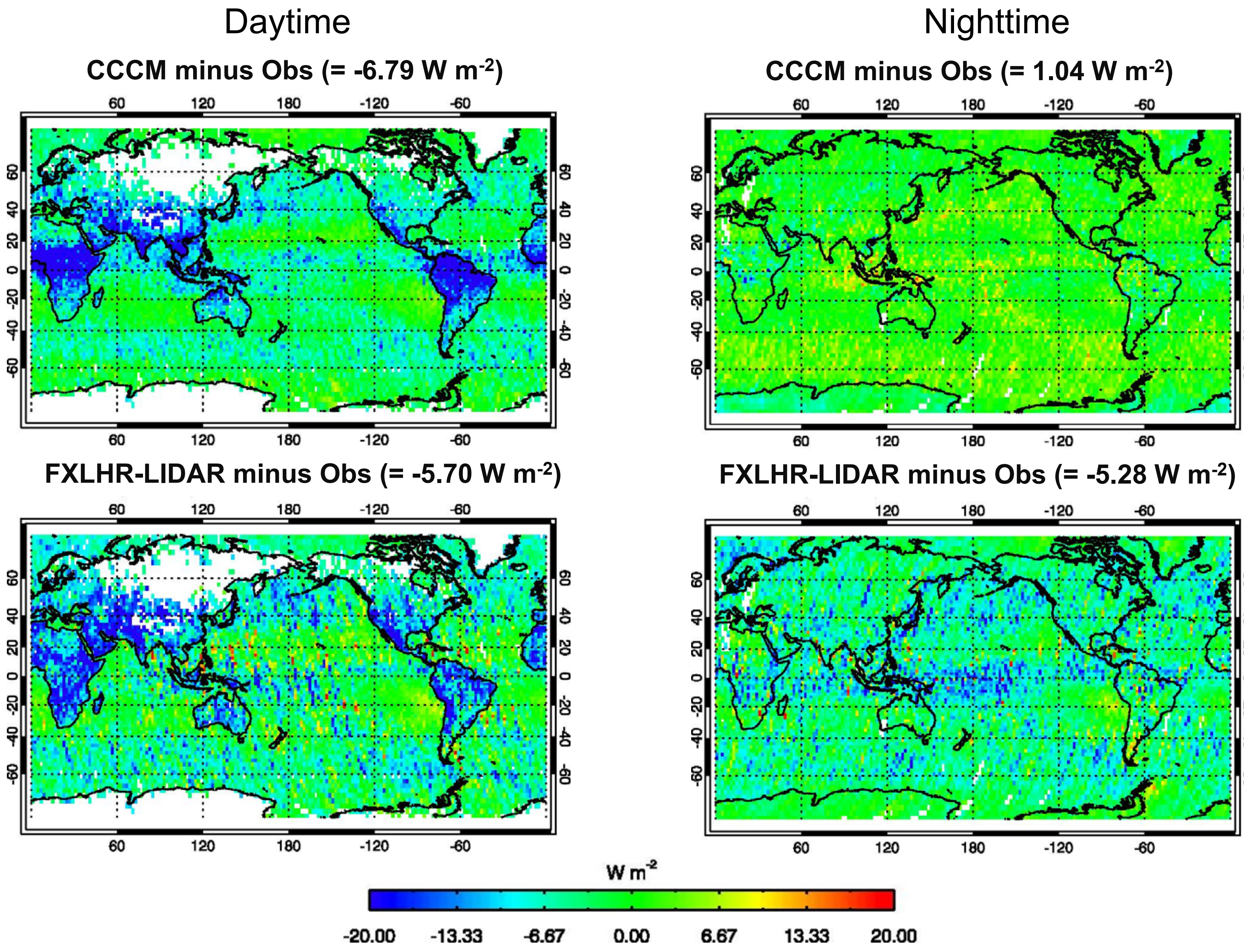
FXLHR-LIDAR



FXLHR-LIDAR minus Obs (= 8.18 W m^{-2})



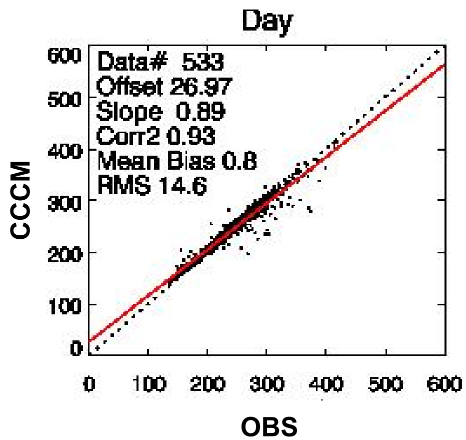
LW Radiative Closure at TOA (Using CERES Observation)

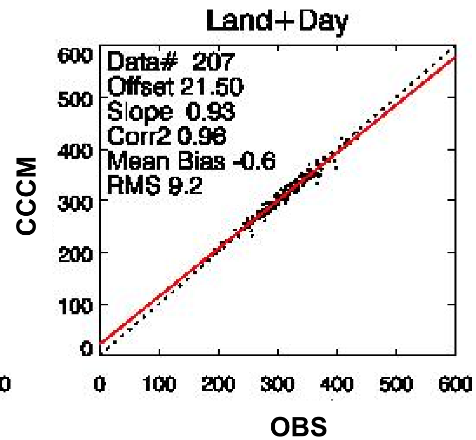


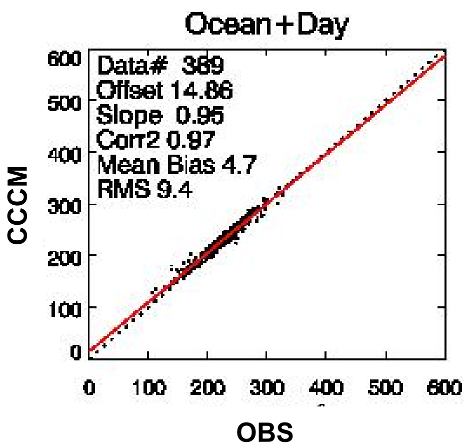
Comparison with CERES SW TOA Measurements (8°-Gridded)

4month data

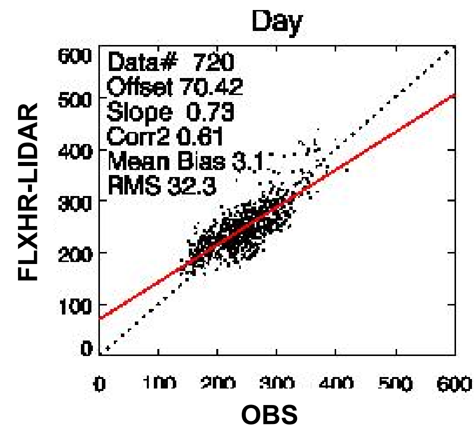
CCCM

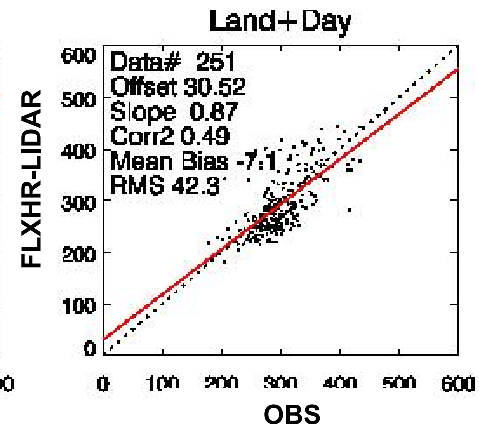


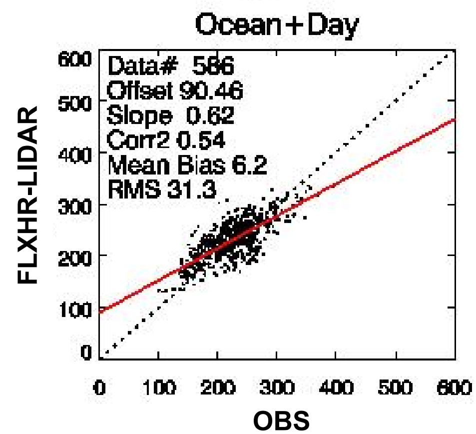




FLXHR-LIDAR



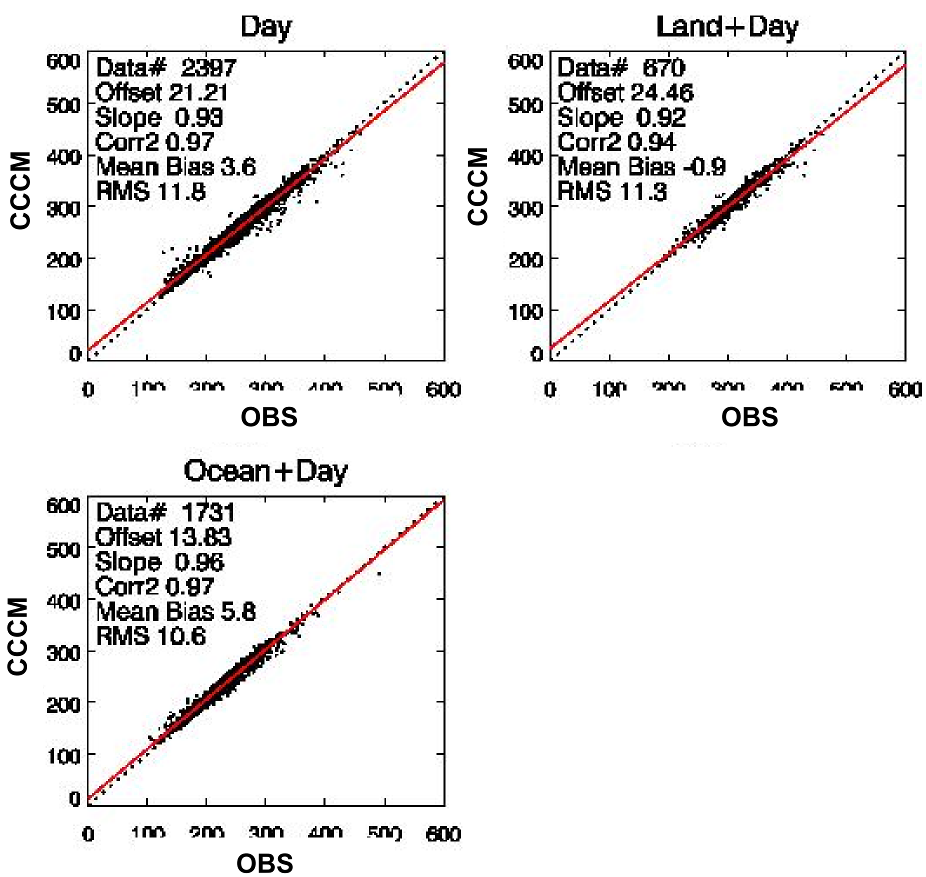




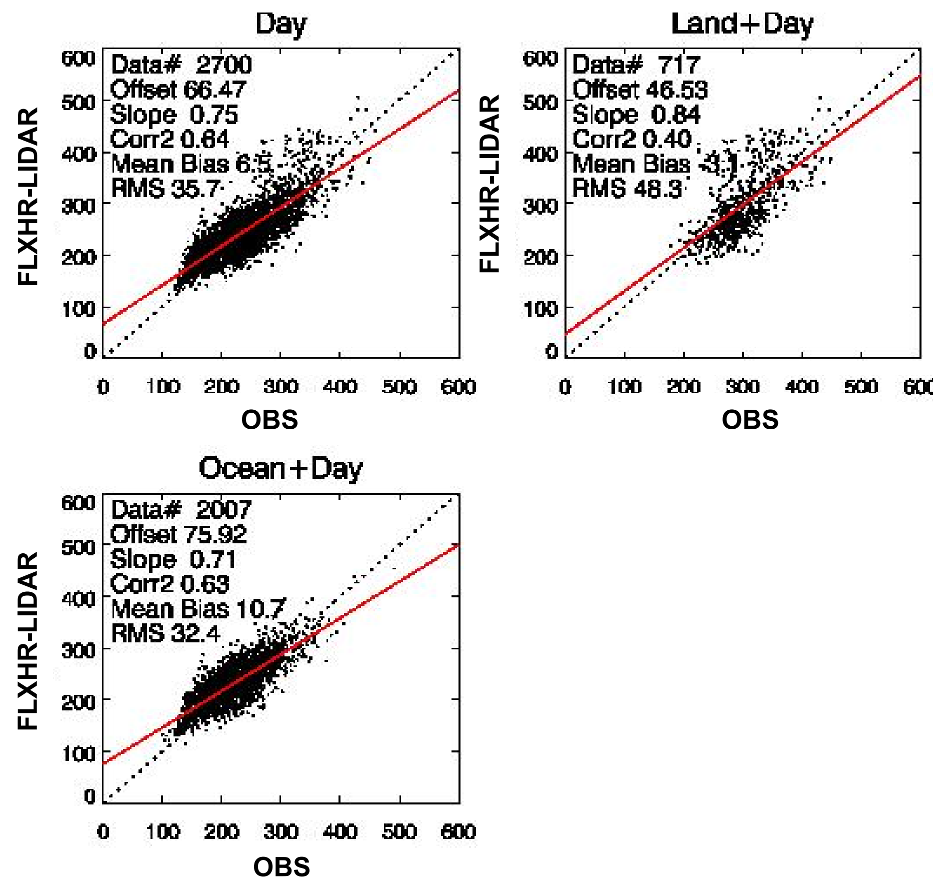
Comparison with CERES SW TOA Measurements (4°-Gridded)

4month data

CCCM



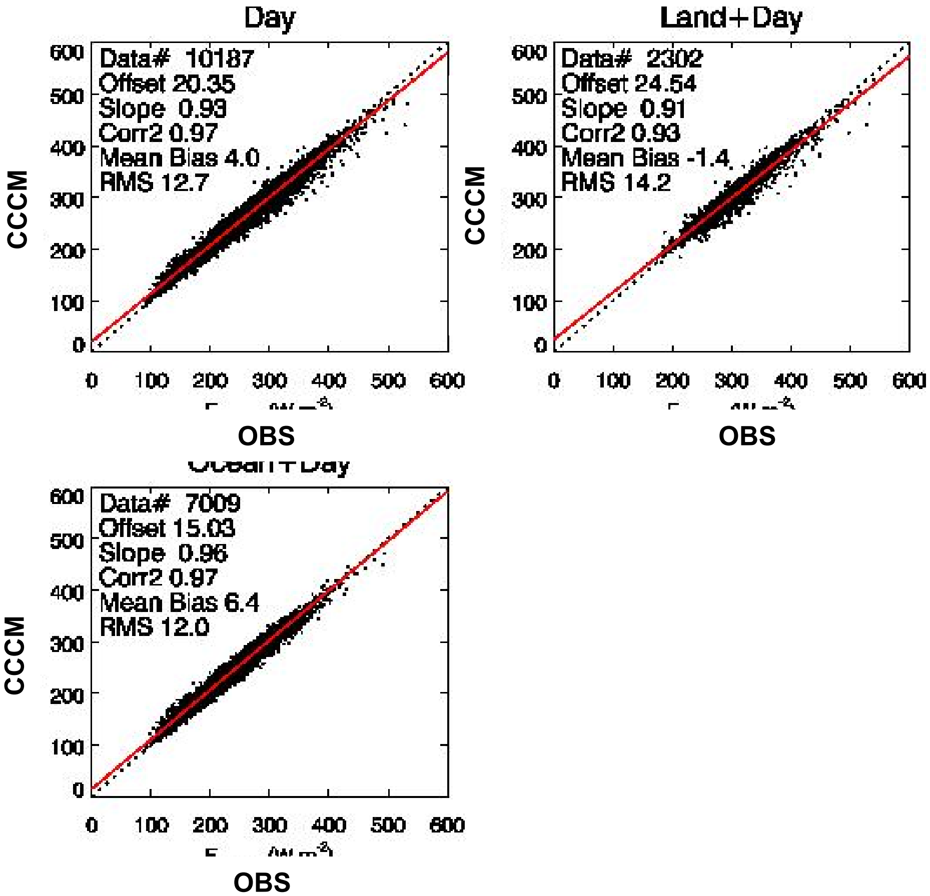
FLXHR-LIDAR



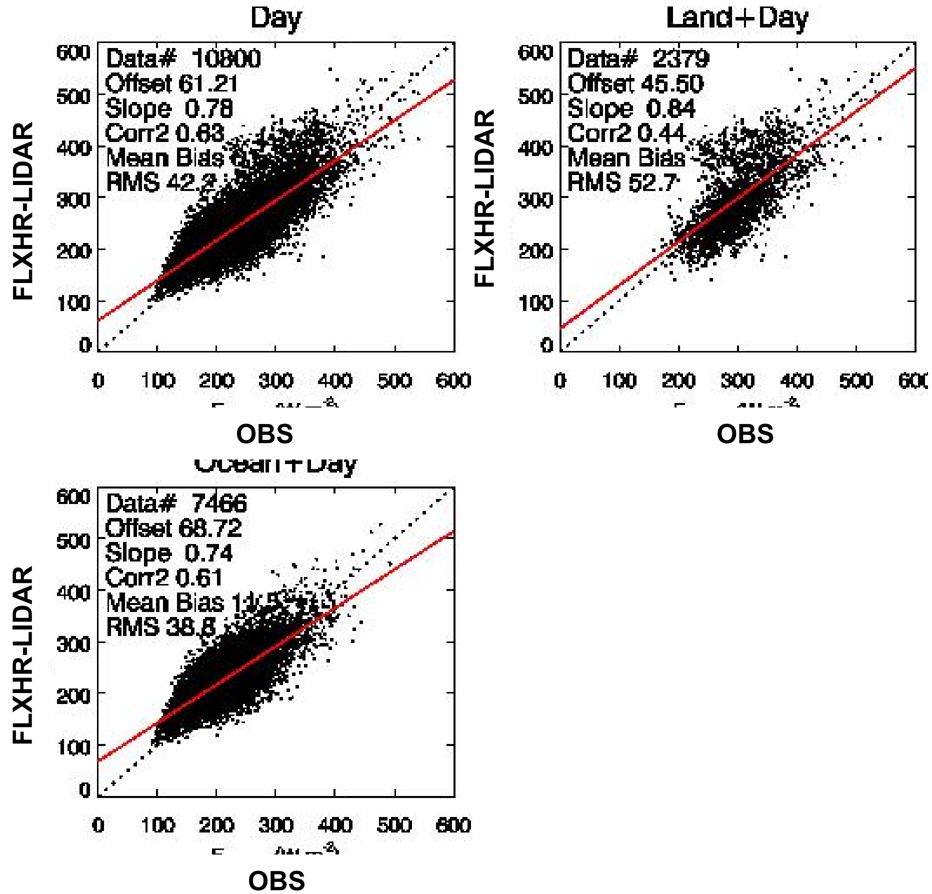
Comparison with CERES SW TOA Measurements (2°-Gridded)

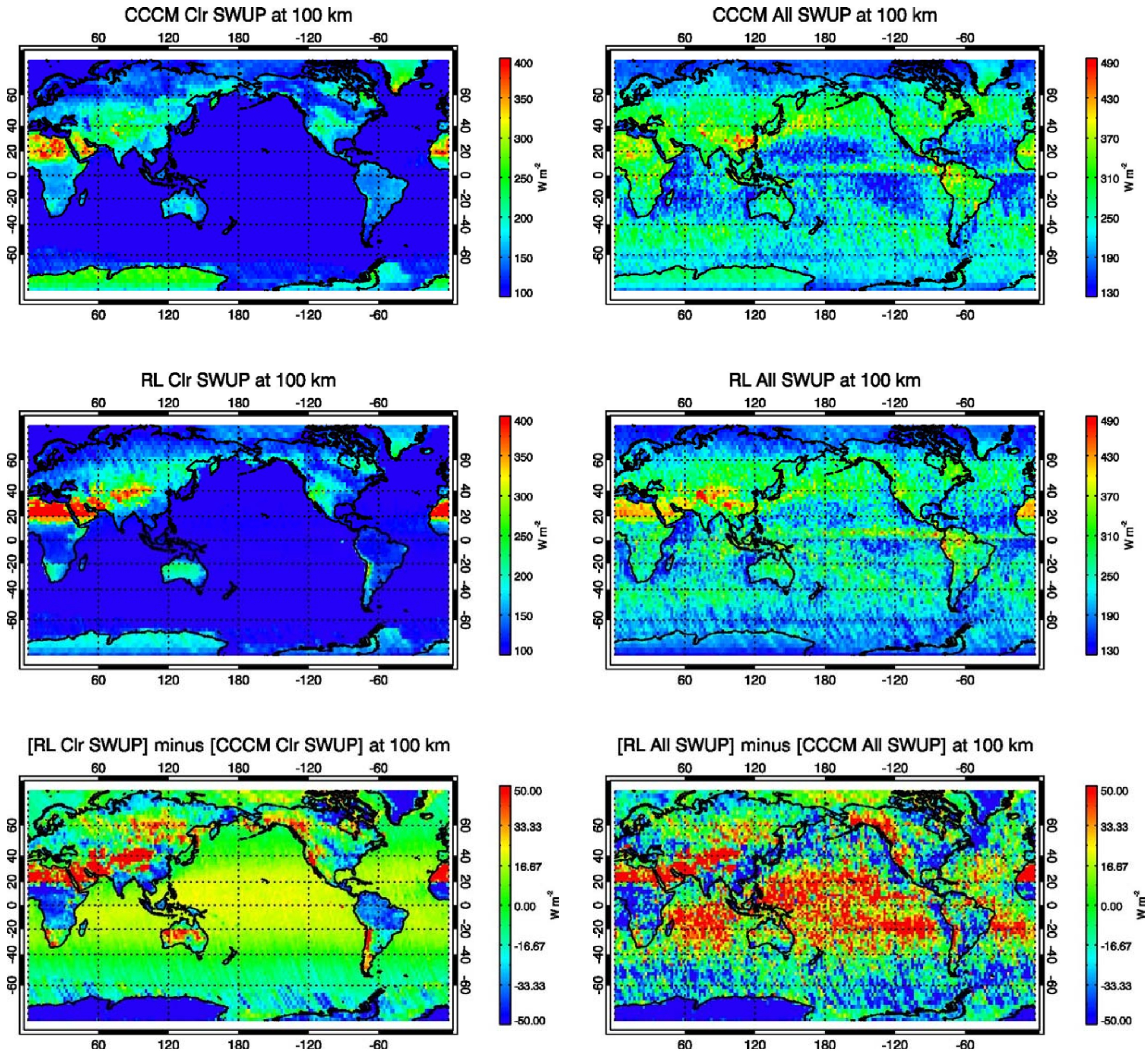
4month data

CCCM

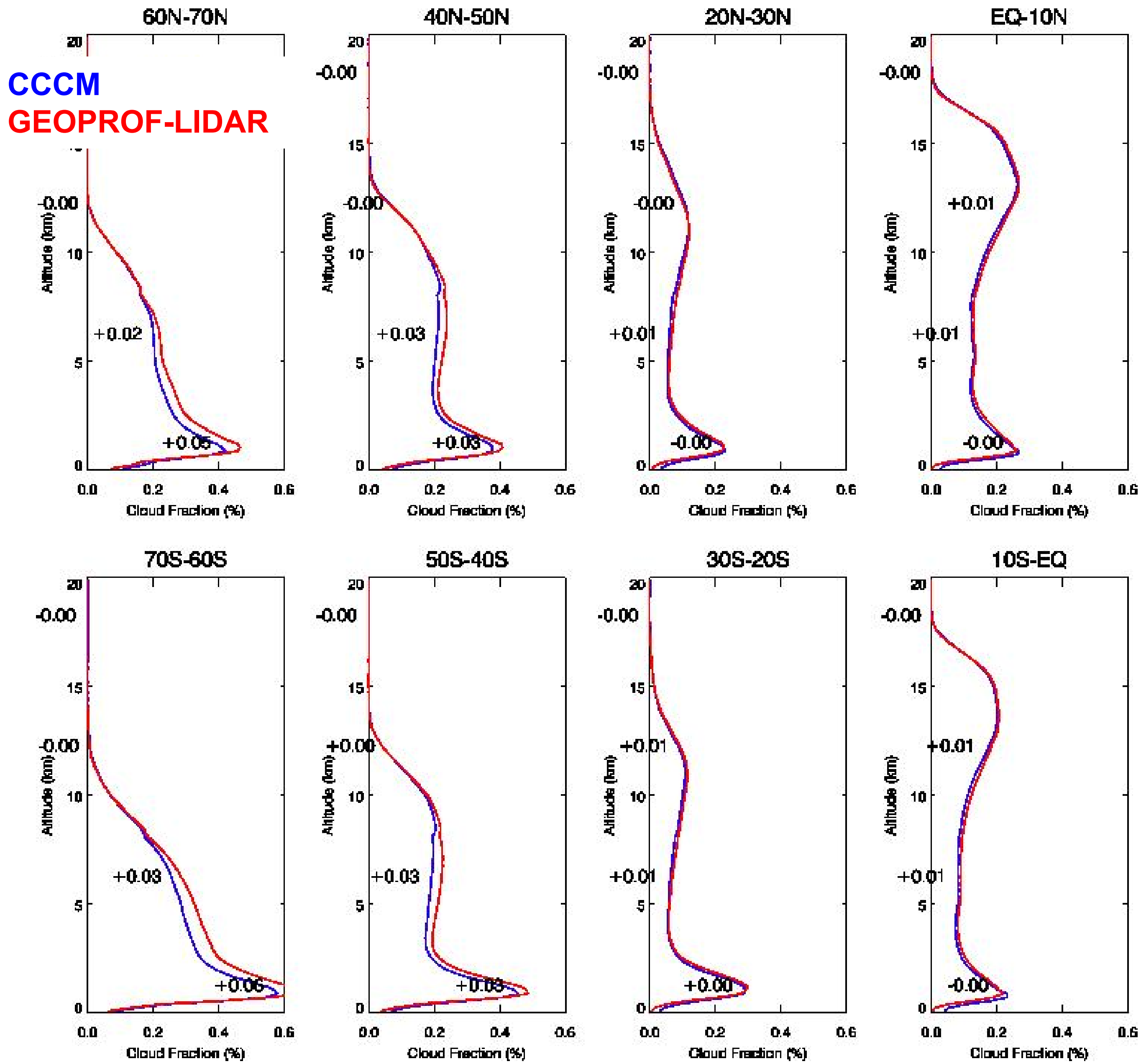


FLXHR-LIDAR

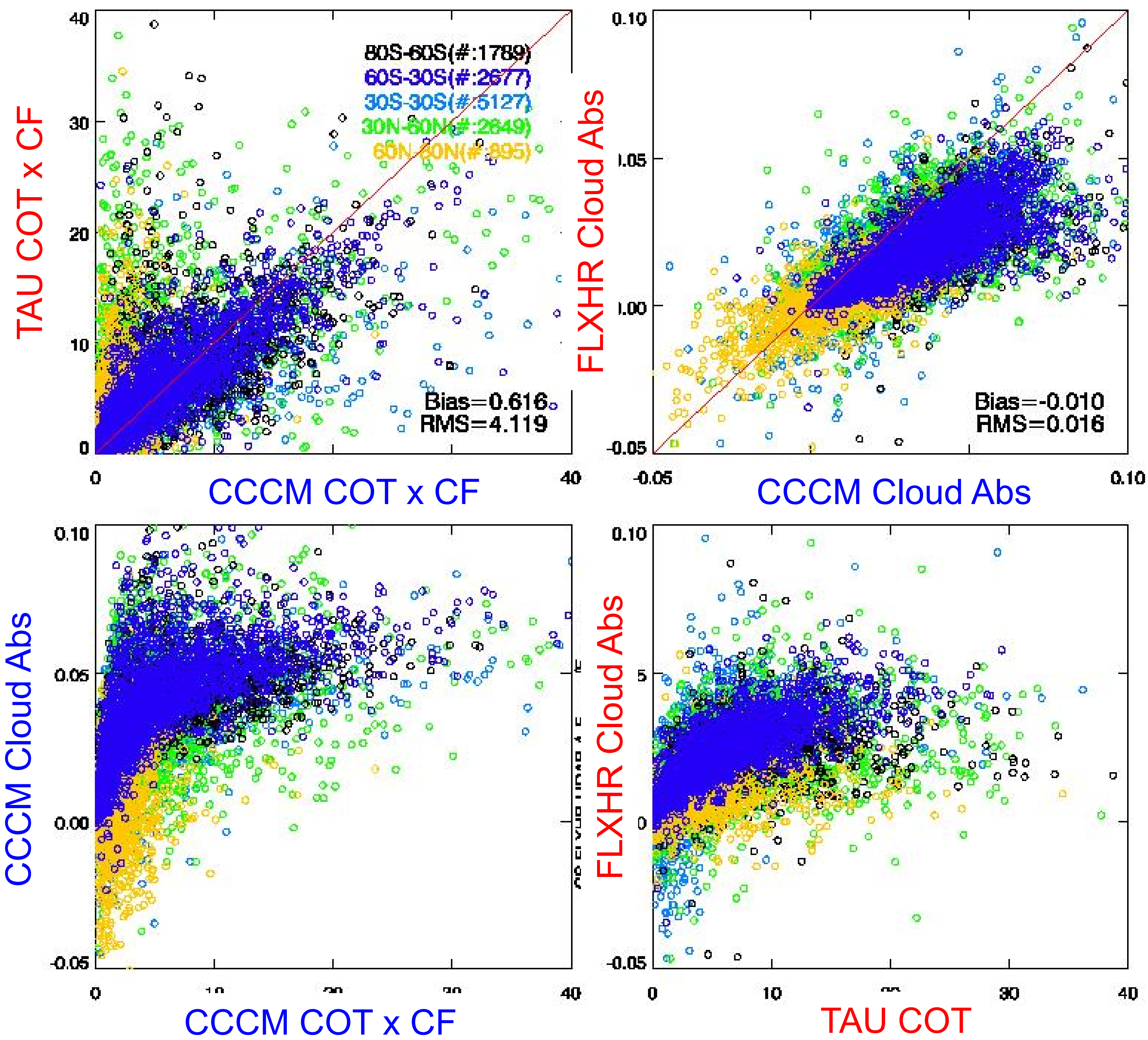



CCCM Clr SWUP at 100 km
CCCM All SWUP at 100 km
RL Clr SWUP at 100 km
RL All SWUP at 100 km
[RL Clr SWUP] minus [CCCM Clr SWUP] at 100 km
[RL All SWUP] minus [CCCM All SWUP] at 100 km
W m^{-2}

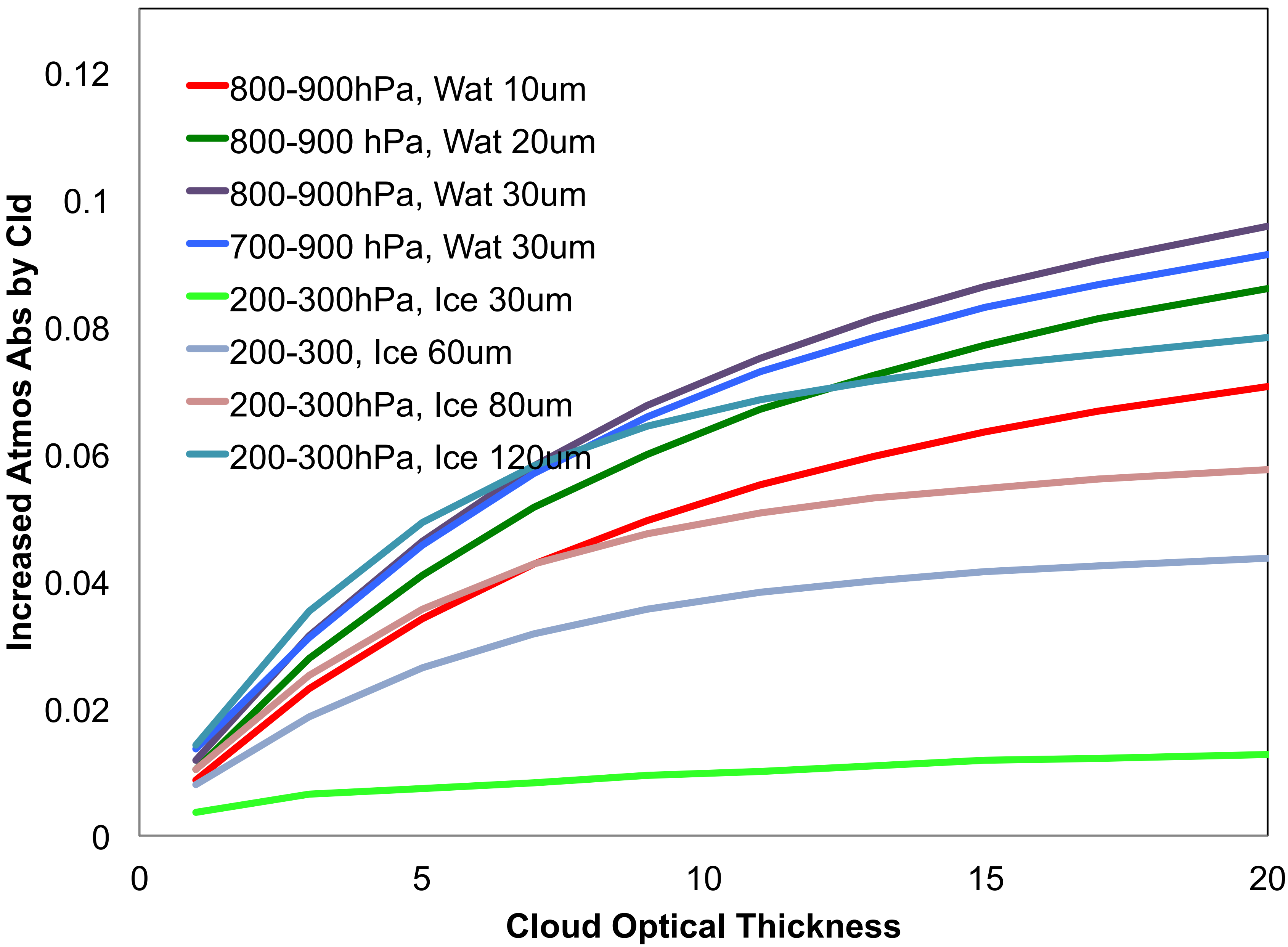
Zonal Mean Cloud Fraction Profiles



Ocean+Day



80S-60S(#:1789)
60S-30S(#:2677)
30S-30S(#:5127)
30N-60N(#:2649)
60N-80N(#:895)
Bias=0.616
RMS=4.119
TAU COT x CF
CCCM COT x CF
Bias=-0.010
RMS=0.016
FLXHR Cloud Abs
CCCM Cloud Abs
CCCM Cloud Abs
CCCM COT x CF
FLXHR Cloud Abs
TAU COT



0.12
0.1
0.08
0.06
0.04
0.02
0
0
5
10
15
20
Increased Atmos Abs by Cld
Cloud Optical Thickness
800-900hPa, Wat 10um
800-900 hPa, Wat 20um
800-900hPa, Wat 30um
700-900 hPa, Wat 30um
200-300hPa, Ice 30um
200-300, Ice 60um
200-300hPa, Ice 80um
200-300hPa, Ice 120um